

# *Northern Eurasia Future Initiative (NEFI): facing the challenges and pathways of global change in the 21st century*

Article

Accepted Version

Groisman, P., Shugart, H., Kicklighter, D., Henebry, G., Tchebakova, N., Maksyutov, S., Monier, E., Gutman, G., Gulev, S., Qi, J., Prishchepov, A., Kukavskaya, E., Porfiriev, B., Shiklomanov, A., Loboda, T., Shiklomanov, N., Nghiem, S., Bergen, K., Albrechtová, J., Chen, J., Shahgedanova, M. ORCID: <https://orcid.org/0000-0002-2320-3885>, Shvidenko, A., Speranskaya, N., Soja, A., de Beurs, K., Bulygina, O., McCarty, J., Zhuang, Q. and Zolina, O. (2017) Northern Eurasia Future Initiative (NEFI): facing the challenges and pathways of global change in the 21st century. *Progress in Earth and Planetary Science*, 4 (1). pp. 2197-4284. ISSN 2197-4284 doi: 10.1186/s40645-017-0154-5 Available at <https://centaur.reading.ac.uk/74037/>

It is advisable to refer to the publisher's version if you intend to cite from the work. See [Guidance on citing](#).

To link to this article DOI: <http://dx.doi.org/10.1186/s40645-017-0154-5>

Publisher: Springer

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

[www.reading.ac.uk/centaur](http://www.reading.ac.uk/centaur)

**CentAUR**

Central Archive at the University of Reading

Reading's research outputs online

1 Northern Eurasia Future Initiative (NEFI): Facing the Challenges and Pathways of Global  
2 Change in the 21<sup>st</sup> Century

3

4 Pavel Groisman<sup>1, 9, 30, \*</sup>

5 Corresponding author

6 Email: pasha.groisman@noaa.gov

7

8 Herman Shugart<sup>2</sup>

9 Email: hhs@virginia.edu

10

11 David Kicklighter<sup>3</sup>

12 Email: dkicklighter@mbl.edu

13

14 Geoffrey Henebry<sup>4</sup>

15 Email: geoffrey.henebry@sdstate.edu

16

17 Nadezhda Tchebakova<sup>5</sup>

18 Email: ncheby@ksc.krasn.ru

19

20 Shamil Maksyutov<sup>6</sup>

21 Email: shamil@nies.go.jp

22

23 Erwan Monier<sup>7</sup>

24 Email emonier@mit.edu

25

26 Garik Gutman<sup>8</sup>

27 Email: ggutman@nasa.gov

28

29 Sergey Gulev<sup>9</sup>

30 Email gul@sail.msk.ru

31

32 Jiaguo Qi<sup>10, 19</sup>

33 Email qi@msu.edu

34

35 Alexander Prishchepov<sup>11, 31</sup>

36 Email alpr@ign.ku.dk

37

38 Elena Kukavskaya<sup>5</sup>

39 Email kukavskaya@ksc.krasn.ru

40

41 Boris Porfiriev<sup>12</sup>

42 Email b\_porfiriev@mail.ru

43

44 Alexander Shiklomanov<sup>13</sup>

45 Email alex.shiklomanov@unh.edu

46

47 Tatiana Loboda<sup>14</sup>

48 Email loboda@umd.edu

49

50 Nikolay Shiklomanov<sup>15</sup>

51 Email shiklom@gwu.edu

52

53 Son Nghiem<sup>16</sup>

54 Email Son.V.Nghiem@jpl.nasa.gov

55

56 Kathleen Bergen<sup>17</sup>

57 Email kbergen@umich.edu

58

59 Jana Albrechtová<sup>18</sup>

60 Email albrecht@natur.cuni.cz

61

62 Jiquan Chen<sup>10, 19</sup>

63 Email jqchen@msu.edu

64

65 Maria Shahgedanova<sup>20</sup>

66 Email m.shahgedanova@reading.ac.uk

67

68 Anatoly Shvidenko<sup>21</sup>

69 Email shvidenk@iiasa.ac.at

70

71 Nina Speranskaya<sup>22</sup>

72 Email speran@mail.rcom.ru

73

74 Amber Soja<sup>23</sup>

75 Email amber.j.soja@nasa.gov

76

77 Kirsten de Beurs<sup>24</sup>

78 Email [kdebeurs@ou.edu](mailto:kdebeurs@ou.edu)

79

80 Olga Bulygina<sup>25</sup>

81 Email [bulygina@meteo.ru](mailto:bulygina@meteo.ru)

82

83 Jessica McCarty<sup>26, 27</sup>

84 Email [jmccarty@mtu.edu](mailto:jmccarty@mtu.edu)

85

86 Qianlai Zhuang<sup>28</sup>

87 Email [qzhuang@purdue.edu](mailto:qzhuang@purdue.edu)

88

89 Olga Zolina<sup>29</sup>

90 Email [olga.zolina@univ-grenoble-alpes.fr](mailto:olga.zolina@univ-grenoble-alpes.fr)

91

92

93 <sup>1</sup> NEESPI Project Scientist, NC State University Research Scholar, at National Centers for  
94 Environment Information, Federal Building, 151 Patton Avenue, Asheville, NC 28801, USA

95 <sup>2</sup> Dept. Environmental Sciences, University of Virginia, 291 McCormick Drive, Charlottesville,  
96 Virginia 22904-4123, USA

97 <sup>3</sup> The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543, USA

98 <sup>4</sup> Geospatial Sciences Center of Excellence, South Dakota State University, 1021 Medary Avenue,  
99 Wecota Hall 506B, Brookings, SD 57007-3510, USA

100 <sup>5</sup> Sukachev Institute of Forest, SB RAS – Federal Research Center “Krasnoyarsk Science Center SB  
101 RAS”, 50/28 Akademgorodok, Krasnoyarsk, 660036, Russia

102 <sup>6</sup> National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan

103 <sup>7</sup> Joint Program of the Science and Policy of Global Change, Massachusetts Institute of Technology,  
104 Cambridge, MA 02139-4307, USA

105 <sup>8</sup> NASA Headquarters, The NASA Land-Cover/Land-Use Change Program, Mail Suite 3B74, Room  
106 3Y77, 300 E Street, SW, Washington, DC 20546, USA

107 <sup>9</sup> P.P. Shirshov Institute of Oceanology, RAS, 36 Nakhimovsky Ave. 117218, Moscow, Russia

108 <sup>10</sup> Department of Geography, Michigan State University, 673 Auditorium Rd, East Lansing, MI  
109 48824, USA

110 <sup>11</sup> Dept. Geosciences and Natural Resource Management, University of Copenhagen, Section of  
111 Geography, Øster Voldgade 10, 1350 København K, Denmark

112 <sup>12</sup> Institute for Economic Forecasting, RAS, 47 Nakhimovsky Ave., 117418, Moscow, Russia

113 <sup>13</sup> Earth Systems Research Center, University of New Hampshire, Morse Hall, 8 College Rd, Rm. 21,  
114 Durham NH 03824, USA

115 <sup>14</sup> Dept. Geographical Sciences, University of Maryland – College Park, 1121 LeFrak Hall, 7251  
116 Preinkert Drive, College Park, MD 20742, USA

117 <sup>15</sup> Dept. of Geography, George Washington University, Old Main Bldg, 1922 F Street, NW,  
118 Washington, DC, 20052, USA

119 <sup>16</sup> Jet Propulsion Laboratory, California Institute of Technology, MS 300-235, 4800 Oak Grove Drive,  
120 Pasadena, CA 91109, USA

121 <sup>17</sup> School of Natural Resources and Environment, University of Michigan, 440 Church St., Ann Arbor,  
122 MI 48109, USA

123 <sup>18</sup> Department of Experimental Plant Biology, Faculty of Science, Charles University in Prague,  
124 Vinicna 5, 128 44 Prague, Czechia

125 <sup>19</sup> Center for Global Change and Earth Observations, Michigan State University, 1405 S. Harrison  
126 Road, East Lansing, MI 48823, USA

127 <sup>20</sup> Department of Geography and Environmental Science, The University of Reading, Whiteknights,

128 Reading, UK, RG6 6AB, United Kingdom  
129 <sup>21</sup> Ecosystems Services and Management Program, International Institute for Applied Systems  
130 Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria  
131 <sup>22</sup> State Hydrological Institute, 2<sup>nd</sup> Lane, Basil Island, St. Petersburg, 199053, Russia  
132 <sup>23</sup> National Institute of Aerospace, NASA Langley Research Center, 21 Langley Boulevard, MS 420,  
133 Hampton, VA 23681, USA  
134 <sup>24</sup> Department of Geography and Environmental Sustainability, University of Oklahoma, 100 East  
135 Boyd Street, SEC Suite 510, Norman OK 73019, USA  
136 <sup>25</sup> Russian Institute for Hydrometeorological Information, 6 Koroleva Street, Obninsk, 249020,  
137 Kaluga Area, Russia  
138 <sup>26</sup> Michigan Tech Research Institute, 3600 Green Court, Suite 100, Ann Arbor, MI 48105 USA  
139 <sup>27</sup> Department of Geography, Miami University, 250 S. Patterson Ave, Oxford, OH 45056  
140 USA  
141 <sup>28</sup> Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907 USA  
142 <sup>29</sup> Lab. de Glaciologie et Géophysique de l'Environnement, Joseph Fourier University - Grenoble 1,  
143 54 rue Moliere, BP 96, 38402 - Saint Martin d'Heres Cedex, France  
144 <sup>30</sup> Hydrology Science and Service Corporation, 920 Rockhold Drive, Asheville, NC, 28804, USA  
145 <sup>31</sup> Institute of Environmental Sciences, Kazan Federal University, Kazan, Tovarishcheskaya str.5,  
146 Kazan, 420097, Russia  
147  
148 \* Corresponding Author, Pavel Groisman, NC State University Research Scholar, at NOAA  
149 National Centers for Environment Information, Federal Building, 151 Patton Avenue,  
150 Asheville, NC 28801, USA. Ph.: +1 828 271-4347; E-mail: [Pasha.Groisman@noaa.gov](mailto:Pasha.Groisman@noaa.gov).

151 **Abstract**

152 During the past several decades, the Earth system has changed significantly, especially across  
153 Northern Eurasia. Changes in the socio-economic conditions of the larger countries in the  
154 region have also resulted in a variety of regional environmental changes that can have global  
155 consequences. The Northern Eurasia Future Initiative (NEFI) has been designed as an  
156 essential continuation of the Northern Eurasia Earth Science Partnership Initiative (NEESPI),  
157 which was launched in 2004. NEESPI sought to elucidate all aspects of ongoing  
158 environmental change, to inform societies and, thus, to better prepare societies for future  
159 developments. A key principle of NEFI is that these developments must now be secured  
160 through science-based strategies co-designed with regional decision makers to lead their  
161 societies to prosperity in the face of environmental and institutional challenges. NEESPI  
162 scientific research, data, and models have created a solid knowledge base to support the NEFI  
163 program. This paper presents the NEFI research vision consensus based on that knowledge. It  
164 provides the reader with samples of recent accomplishments in regional studies and  
165 formulates new NEFI science questions. To address these questions, nine research foci are  
166 identified and their selections are briefly justified. These foci include: warming of the Arctic;  
167 changing frequency, pattern, and intensity of extreme and inclement environmental  
168 conditions; retreat of the cryosphere; changes in terrestrial water cycles; changes in the  
169 biosphere; pressures on land-use; changes in infrastructure; societal actions in response to  
170 environmental change; and quantification of Northern Eurasia's role in the global Earth  
171 system. Powerful feedbacks between the Earth and human systems in Northern Eurasia (e.g.,  
172 mega-fires, droughts, depletion of the cryosphere essential for water supply, retreat of sea ice)  
173 result from past and current human activities (e.g., large scale water withdrawals, land use and  
174 governance change) and potentially restrict or provide new opportunities for future human  
175 activities. Therefore, we propose that Integrated Assessment Models are needed as the final

176 stage of global change assessment. The overarching goal of this NEFI modeling effort will  
177 enable evaluation of economic decisions in response to changing environmental conditions  
178 and justification of mitigation and adaptation efforts.

179

180 **Keywords**

181 Environmental Changes, Northern Eurasia, Ecosystems dynamics, Terrestrial water cycle,  
182 Cryosphere retreat, Extreme and inclement environmental conditions, Sustainable  
183 development, Land-cover and land-use change, Integrated assessment models for decision-  
184 makers

185

186 **Introduction**

187 Northern Eurasia Future Initiative (NEFI) was conceived at the Workshop “*Ten years of*  
188 *Northern Eurasia Earth Science Partnership Initiative (NEESPI): Synthesis and Future*  
189 *Plans*” hosted by Charles University in Prague, Czech Republic (April 9-12, 2015). That  
190 event was attended by more than 70 participants from Japan, China, Russia, Ukraine,  
191 Kyrgyzstan, Kazakhstan, the European Union, and the United States. The workshop included  
192 an overview, synthesis presentations, and scientific visions for NEESPI in its transition to  
193 NEFI. These results (<http://neespi.org/web-content/PragueWorkshopSynthesisBriefing.pdf>)  
194 were delivered at a dedicated open public Splinter Meeting at the European Geophysical  
195 Union Assembly in Vienna, Austria (April 16<sup>th</sup>, 2015). On May 20, 2016, a NEFI White  
196 Paper was released for public consideration on the NEESPI web site and four months later,  
197 after accounting for numerous comments and recommendations, it was finalized and posted at  
198 <http://nefi-neespi.org/>. The current paper presents the consensus of the future NEFI vision to  
199 address the challenges facing the region, and to develop pathways to mitigate future  
200 problematic changes.

201 During the past 12 years, NEESPI has been quite successful at conducting and  
202 advancing research within its large geographical domain of Northern Eurasia (Figure 1;  
203 Groisman and Bartalev 2007). The NEFI research domain is the same. The NEESPI program  
204 accommodated 172 projects focused on different environmental issues in Northern Eurasia.  
205 More than 1500 peer-reviewed journal papers and 40 books were published during the past  
206 decade (<http://nefi-neespi.org/science/publications.html>; Groisman et al. 2009, 2014;  
207 Groisman and Soja 2009). Several overview books further synthesized findings (Gutman and  
208 Reissell, 2011; Groisman and Lyalko 2012; Groisman and Gutman 2013; Chen et al. 2013;  
209 Gutman and Radeloff 2016). While the initial duration of the NEESPI research program was

210 estimated to be 10–12 years, its momentum has exceeded original expectations. In addition to  
211 accumulating knowledge and publishing scientific journal papers and books, NEESPI  
212 scientists developed new observations, datasets, data networks, tools and models. As a result,  
213 a new research realm emerged for studies in Northern Eurasia, and we are now poised to  
214 apply these results to directly support decision-making for various coupled environmental-  
215 societal needs.

216 **Figure 1.**

217 The past accomplishments are not the only driver for the proposed NEFI initiative.  
218 Just as, or perhaps even more importantly, NEFI will address two significant and intertwined  
219 changes that have emerged. These are: 1) continued and exacerbated change in the global  
220 Earth and climate system, and 2) societal change and stress with a heightened need for  
221 mitigation and adaptation approaches. With respect to the first, the global Earth system has  
222 significantly changed, with the changes in Northern Eurasia being substantially larger than the  
223 global average (cf., Figures 2 and 3). Subsequently, one NEFI endeavor is to analyze this *new*  
224 *state* with its unexpected novel features and distributions. These novel characteristics include  
225 shifts of the seasonal cycle for various climatic functions to changes in intensity, frequency,  
226 and spatial patterns and temporal trends of extreme events. These changes have already  
227 occurred, but their impacts on (and feedbacks to) atmospheric, biospheric, cryospheric,  
228 hydrologic, oceanic, and macro-socioeconomic processes are ongoing.

229 **Figure 2.**

230 **Figure 3.**

231 The second significant change that NEFI will need to address concerns the socio-economic  
232 dynamics in the major nations of Northern Eurasia. These dynamics have also dramatically  
233 changed, including the ability of societies to withstand and adapt to the adverse

234 manifestations of the above-described environmental changes. Fundamental to addressing  
235 this is the sound scientific understanding and quantification of the amount of Earth system  
236 change that societies are currently experiencing and may experience by the end of the 21<sup>st</sup>  
237 century. However, in addition to understanding the scientific basis, communities (and even  
238 nations) have increasingly begun to inquire about what mitigation and/or adaptation strategies  
239 are possible for the upcoming decades. These types of questions need to be addressed  
240 differently, because societal decision-making impacts the environment, which feeds back to  
241 influence future societal decision-making. The major anthropogenic causes of global change  
242 remain ongoing. Thus, the Earth science community and society in general will need to be  
243 informed and prepared to assure a sustainable future.

244 The results of scientific research, data, and models accumulated during the past decade  
245 will allow us to build upon this knowledge to directly support decision-making activities that  
246 address societal needs in Northern Eurasia. During the last decade, substantial climatic and  
247 environmental changes have already been quantified. While natural processes (except the  
248 high amplitude of their variations) are mainly the same as in other parts of the World, human  
249 factors and changes in land cover and land use in the NEFI domain during the past decades  
250 were dramatic and unique. Changes in the socio-economics of major nations in the region  
251 have ultimately transformed human-environment interactions. This in turn has transformed  
252 regional land cover and water resources towards conditions that endanger or even overcome  
253 the resilience of natural ecosystems (e.g., disappearing lakes and runoff diversions,  
254 deforestation, degradation and abandonment of agriculture fields and pasture; air, soil, and  
255 water pollution). These and projected changes will require expeditious direct responses on  
256 behalf of human well-being and societal health in order to move toward a sustainable future.

257 Therefore, the core motivation of NEFI is to best use science to serve the decision-  
258 making process to maintain Earth system health and to sustain society. In the next two

259 sections, we:

260 • Formulate three major science questions of global concern associated with unique features

261 of Northern Eurasia,

262 • Formulate the major research foci for the next decade that, as the NEFI Science Plan

263 authors believe, are of crucial importance to be addressed expediently, and

264 • Examine and justify the issues related to these research foci in more detail.

265 An approach to regional studies in Northern Eurasia based on integrated assessment modeling

266 is described and justified in the last section of the paper. Because this paper is an overview of

267 a large amount of relevant findings from the past decade, we also provide a comprehensive

268 list of references to those works.

269

## 270 **REVIEW**

### 271

### 272 **Three unique features of Northern Eurasia of global concern and their**

### 273 **related major science questions**

274

275 To develop effective mitigation and adaptation strategies, future NEFI activities will need to

276 consider three unique features of Northern Eurasia: 1) the sensitivity of land surface

277 characteristics to global change that feedback to influence the global energy budget; 2)

278 potential changes in the Dry Land Belt of Northern Eurasia (DLB) that will have a large

279 influence on the availability of water for food, energy, industry, and transportation; and 3)

280 evolving social institutions and economies. Below, we look at these features in more detail

281 and suggest that three major science questions emerge from this examination.

282

### 283 **Sensitivity of land surface characteristics to global change**

284 The Arctic, Arctic Ocean shelf, and the Boreal Zone of Eurasia are areas of substantial  
285 terrestrial carbon storage in wetlands, soil, boreal forest, terrestrial and sea shelf permafrost.  
286 From these emerge powerful carbon-cryosphere interactions and variability that intertwine  
287 with strong climatic and environmental changes (Figure 4). These interactions also can  
288 generate positive feedback to Earth system changes via both biogeochemical (atmospheric  
289 composition, water quality, plant and microbial metabolism) and biogeophysical impacts  
290 (surface albedo, fresh water budget, and thermohaline circulation of the World Ocean). These  
291 intertwined linkages and feedbacks may increase the rate of global (or near-global) change  
292 and/or increase uncertainties about that change. In turn, this places the wellbeing of societies  
293 at risk if planned mitigation and adaptation measures are not implemented in a sound and  
294 timely fashion.

295 **Figure 4.**

296 Thus, in future studies within Northern Eurasia, special attention should be paid to the  
297 changes on the volatile boundaries of the Arctic, boreal, and dry zones. The highly variable  
298 components of the cryosphere (seasonal snow cover) which are vitally controlled by  
299 components that have been systematically changing (e.g., glaciers and permafrost) should be  
300 recognized. The rates of change due to catastrophic forest fires (Conard et al. 2002;  
301 Goldammer 2013), dust storms (Goudie and Middleton 1992; Sokolik 2013), and  
302 controversial future methane release from frozen ground in high latitudinal land and shelf  
303 areas (Kirschke et al. 2013; Shakhova et al. 2013, 2015; Zhu et al. 2013; Ruppel and Kessler  
304 2017) must be accounted for or ameliorated.

305 *Based on the above, the first Major Science Question is: “How can we quantify and  
306 project ecosystem dynamics in Northern Eurasia that influence the global energy budget  
307 when these dynamics are internally unstable (e.g., operate within narrow temperature*

308 *ranges), are interrelated and have the potential to impact the global Earth system with*  
309 *unprecedented rates of change?"*

310

### 311 **Water availability and the dry land belt of Northern Eurasia**

312 The interior of the Earth's largest continent is mostly cut off from water vapor transport from  
313 the tropics by mountain ridges and plateaus spread across the central regions of Asia, thus  
314 creating the Dry Land Belt of Northern Eurasia (DLB; Figure 1). The DLB is the largest dry  
315 area in the extratropics and may be expanding northward (Shuman et al. 2015; Figure 4) as it  
316 has done in past millennia (Chen et al. 2008, 2010; Kozharinov and Borisov 2013). Parts of  
317 the DLB are quite densely populated (e.g., Northern China, Central Asia) and have fertile  
318 land. For example, the Pannonian Lowland and the black soils in Ukraine and European  
319 Russia provide substantial grain export to the global market.

320 However, the DLB has strong physical limitations in the production of crops. It has a  
321 very limited fresh water supply, which is highly dependent upon irregular extra-tropical  
322 cyclones (mostly from the North Atlantic) and a shrinking regional cryosphere. Increases in  
323 evapotranspiration arising from increases in warm season temperatures and expansions of the  
324 growing season in the DLB are generally not compensated by precipitation increase. Further,  
325 changes in the spatio-temporal shifts in precipitation pattern increase the probability of  
326 various unusual or extreme events affecting the livelihoods of regional societies and their  
327 interactions with the global economy (e.g., Henebry et al. 2013; Chen et al. 2015a). This  
328 region is a source of dust storms that can adversely impact the environment, climate, and  
329 human well-being (Darmenova et al. 2009).

330 *Arising from these considerations, the second Major Science Question is: "What are*  
331 *the major drivers of the ongoing and future changes in the water cycles within the regions of*

332 *Northern Eurasia with insufficient water resources (i.e., DLB and its vicinity)?*” In addressing  
333 this question, future studies should examine how changes in the water cycle will affect  
334 regional ecosystems and societies, and how these changes will feedback to the Earth system  
335 and the global economy.

336 **Evolving social institutions and economies**

337 Institutional changes in Northern Eurasia that have taken place over the past few decades have  
338 led to large changes in the socio-economic fabric of the societies in the region, affecting land  
339 use and the natural environment (cf., Lerman et al. 2004). One overarching challenge has  
340 been the transition from command-driven to “transitional” and more market-driven economics  
341 in the countries of Northern Eurasia. This phenomenon has occurred at different rates, with  
342 differing levels of success, and often with societal costs. This has created unexpected  
343 economic and environmental problems but also opportunities (Bergen et al. 2013; Gutman  
344 and Radeloff 2016). Environmental changes and their related problems include massive  
345 agricultural land abandonment (Alcantara et al. 2013; Griffiths et al. 2013; Wright et al.  
346 2012), inefficient and illegal forest logging (Kuemmerle et al. 2009; Knorn et al. 2012;  
347 Newell and Simeone 2014), degradation of cultivated and pasture lands (Ioffe et al. 2012;  
348 Chen et al. 2015a, 2015b), growing water deficits and drought (especially in the DLB and  
349 new independent states), and the spread of human-induced fires (Soja et al. 2007; McCarty et  
350 al. 2017). Many of these outcomes have become important concerns with policy implications  
351 at the national and intergovernmental levels. Opportunities emerge mostly with advances of  
352 warmer climate conditions northward (agriculture benefits at high latitudes, better  
353 transportation conditions in the Arctic Seas; Tchebakova et al. 2011). Other opportunities are  
354 institutional, such as cooperation between nations and non-profit organizations in attempting  
355 to implement forestry certification.

356 Furthermore, the countries of Northern Eurasia with these “transitional” economies are  
357 playing an increasingly important role in the world economic system. Thus, they face further  
358 challenges in highly competitive economic conditions under the additional stresses of  
359 climatic, environmental, and internal societal change. For countries and/or regions with  
360 resource-rich lands and low population (e.g., Russia, Kazakhstan, Mongolia, and  
361 Turkmenistan), their development continues to depend on natural resources inclusive  
362 especially of timber, oil/gas, mining, fisheries, agriculture and hydropower (Bergen et al.  
363 2013). Other countries (e.g., China and Japan) with very large populations and strained or  
364 limited resources (such as available domestic timber in China or Japan) may be strong  
365 consumers of natural resources from elsewhere in Northern Eurasia (Newell and Simeone  
366 2014).

367 Considering the triad "climate – environmental – socio-economic impacts", past  
368 NEESPI investigations sufficiently embraced regional climate diagnostics and, to a somewhat  
369 lesser extent, diagnostics of environmental and ecosystem characteristics. However, the socio-  
370 economic impacts of variability and/or systematic changes in climate and environmental  
371 variables are still poorly defined. This makes it difficult to effectively plan for the future or to  
372 accurately interpret prospective actions based on existing model experiments. These model-  
373 based projections of climate and environmental changes still have to be attributed to and  
374 associated with the mid-term and long-term strategies for the development of different sectors  
375 of the economy including agriculture and grazing, forestry, fisheries, mining, energy, and on-  
376 shore and off-shore infrastructure development. This will be an important NEFI endeavor.

377 *The third Major Science Question is: “How can the sustainable development of*  
378 *societies of Northern Eurasia be secured in the near future (the next few decades)? In*  
379 *addressing this question, future studies should examine how societies can overcome the*

380 “transitional” nature of their economic, environmental and climatic change challenges, and  
381 resolve counterproductive institutional legacies.

382

383 **Major research foci: Why do they matter?**

384 During the preparation and review of the NEFI Science Plan, the directions of future research  
385 over Northern Eurasia have been analyzed in light of the new information gained from past  
386 NEESPI activities, the apparent need to advance further in these directions addressing the  
387 latest dynamics of environmental and socio-economic changes, and the unique features of  
388 Northern Eurasia that are of global concern. Nine major research foci have been identified as  
389 NEFI priorities (listed in no specific order):

- 390 1. Influence of global change, with a focus on warming in the Arctic;
- 391 2. Increasing frequency and intensity of extremes (e.g., intense rains, floods, droughts,  
392 wildfires) and changes in the spatial and temporal distributions of inclement weather  
393 conditions (e.g., heavy wet snowfalls, freezing rains, untimely thaws and peak  
394 streamflow);
- 395 3. Retreat of the cryosphere (snow cover, sea ice, glaciers, and permafrost);
- 396 4. Changes in the terrestrial water cycle (quantity and quality of water supply available for  
397 societal needs);
- 398 5. Changes in the biosphere (e.g., ecosystem shifts, changes in the carbon cycle, phenology,  
399 land-cover degradation and dust storms);
- 400 6. Pressures on agriculture and pastoral production (growing supply and demand, changes in  
401 land use, water available for irrigation, and food-energy-water security);
- 402 7. Changes in infrastructure (roads, new routes, construction codes, pipelines, risks with  
403 permafrost thawing, air, water, and soil pollution);

404 8. Societal adaptations and actions to mitigate the negative consequences of environmental  
405 changes and benefit from the positive consequences; and

406 9. Quantification of the role of Northern Eurasia in the global Earth and socioeconomic  
407 systems to advance research tools with an emphasis on observations and models.

408 Socio-economic research challenges are the top priority for several of these foci. These  
409 challenges have not been overlooked in the past but have not been addressed satisfactorily in  
410 the NEESPI domain, nor indeed globally. The introduction of the Future Earth research  
411 objectives is a response to this gap (<http://www.futureearth.org/>). There is an urgent need to  
412 incorporate socio-economic studies into regional programs by linking the findings of  
413 diagnostic and model-based climate and environmental analyses with the requirements for the  
414 regional infrastructure, which arise from the detailed treatment of socio-economic conditions.

415 We are establishing this strategy as the foundation for the Northern Eurasia Future  
416 Initiative (NEFI) and expect that it will bridge climate and environmental studies with the  
417 economic consequences of the observed changes. This will spur advances in physical  
418 sciences to better quantify observed and projected climate and environmental changes and  
419 improve economic analyses of impacts. This new strategy will directly benefit many  
420 stakeholders and end-users. It will provide them with recommendations and assessments  
421 going far beyond those based exclusively on the analysis of climate and environmental  
422 variables. It will also provide them with a new suite of modeling tools and new data sets to  
423 enable much better and smarter decision making. Furthermore, this strategy will provide a  
424 strong feedback on further planning of climate and environmental studies, pointing to the  
425 parameters, phenomena and mechanisms which, so far, have not been studied and quantified  
426 to a full extent. This will make it possible to revisit and comprehensively review the 12-year  
427 NEESPI legacy in order to transform conventional climate and environmental metrics to those

428 relevant for building more effective economic strategies and risk assessments.

429 Below, we examine and justify the issues related to the above nine major research foci in  
430 more detail, and in the final section propose an integrated assessment modeling approach that  
431 would allow NEFI to eventually address them as best as current technology and knowledge  
432 will support.

433

434 **Research focus 1: global change and the Arctic**

435 Global changes are ongoing and until the causes of these changes are eliminated or mitigated,  
436 there are no expectations that they will slow down (Intergovernmental Panel on Climate  
437 Change (IPCC) 2014; Barros et al. 2014; Karl et al. 2015; see also Figure 2). Regionally, the  
438 temperature changes in Northern Eurasia have been amongst the largest (Blunden and Arndt  
439 2015, 2016). Additionally, there are special reasons to list the changes in the Arctic among  
440 major concerns for future environmental well-being in the extratropics. This small sliver of  
441 the globe (the zone north of 60°N occupies only 7% of the Globe surface) plays an important  
442 role in the global climate. Its air temperature changes during the past decade were  
443 unprecedented for the period of instrumental observations (Figure 5, left) and well above the  
444 2°C warming threshold set by the recent United Nations Climate Change Conference  
445 (November 30–December 12, 2015, Paris, France).

446 There are two major consequences of Arctic warming: (a) changes in the Arctic sea  
447 ice and (b) changes in the meridional gradient of air temperature. The Arctic has become  
448 increasingly closely interlinked with the polar atmosphere with the ongoing retreat and  
449 thinning of the sea ice (Figure 5, right; Renner et al. 2014). The depletion of sea ice increases  
450 the heat and water vapor exchange with the atmosphere, especially during the cold season  
451 (i.e., from mid-September through early June), affecting weather, climate, and the water cycle

452 across the extratropics and, possibly, over the entire hemisphere (Drozdov 1966; Newson  
453 1973; Groisman et al. 2003, 2013a; Arctic Climate Impact Assessment 2005; AMAP 2011;  
454 Bulygina et al. 2013). There are direct practical implications for transportation, regional  
455 infrastructure development and maintenance, and fisheries (AMAP 2011; Farré et al. 2014;  
456 Strategic Assessment of Development of the Arctic 2014; Streletskeiy et al. 2015a).

457 **Figure 5.**

458 The Arctic is closely interlinked with the North Atlantic Ocean. Together they control  
459 the World Ocean thermohaline circulation, which provide most of the cold water influx into  
460 the deep ocean. They define the climate of the northern extratropics (especially the regions  
461 adjacent to the North Atlantic) due to intense meridional heat and mass exchange of the  
462 atmosphere with the ocean in the Atlantic Sector of the Arctic and the subsequent transport of  
463 air masses inside the continents. This exchange is modulated by variations of the Arctic  
464 Oscillation, a large scale mode of climate variability, also referred to as the Northern  
465 Hemisphere annular mode (Thompson and Wallace 1998). All together, they create strong  
466 deviations from the zonal temperature distribution (for example, compare the climate of  
467 Edinburgh, Scotland, UK with Churchill, Canada and Yakutsk, Russia) and are highly  
468 volatile. Relatively small deviations of the oceanic salinity and sea ice distribution in the  
469 northernmost Atlantic may affect the deep water formation process with adverse global  
470 consequences for oceanic circulation (Gulfstream) and climate of the extratropics (LeGrande  
471 et al. 2006). The ongoing decrease of the meridional temperature gradient in the cold season  
472 (Groisman and Soja 2009) may weaken westerlies, causing cold winter outbreaks in the  
473 interior of the continent, larger meandering of the cyclone trajectories over the extratropics  
474 (Francis and Vavrus 2012), and increasing probability of blocking events (Lupo et al. 1997;  
475 Semenov 2012; Mokhov et al. 2013a; Schubert et al. 2014) that can devastate regional  
476 agriculture through the combination of harsh winters and summer heatwaves (Wright et al.

477 2014).

478

479 **Research focus 2: frequency and intensity of extremes**

480 There is already evidence of climate-induced change across Northern Eurasia during the past  
481 few decades (Soja et al. 2007; Groisman and Gutman 2013; Rimkus et al. 2013; Shvidenko  
482 and Schepaschenko 2013; Valendik et al. 2014) with southern regions being particularly  
483 vulnerable to climate change and fires (Malevsky-Malevich et al. 2008). First, there has been  
484 an increase in rainfall intensity and prolonged no-rain periods (summarized in Groisman et al.  
485 2013b; see also Zhai et al. 2004 and Chen and Zhai 2014), which at times may occur in the  
486 same region. Second, an increase in extraordinary temperature anomalies has been  
487 accompanied by summer droughts (Barriopedro et al. 2011; Lei 2011; Lupo et al. 2012;  
488 Bastos et al. 2014; Horion et al. 2016). Third, cold outbreaks and/or thaws have increased  
489 during winter (Arctic Climate Impact Assessment 2005; Groisman et al. 2016). Fourth, an  
490 increase in the frequency of large and severe wildfires has occurred (Conard et al. 2002; Soja  
491 et al. 2007; Kukavskaya et al. 2013b; Shvidenko and Schepaschenko 2013). Finally, intense  
492 dust storms have occurred (Xi and Sokolik 2015a). Official Russian statistics on “dangerous  
493 meteorological phenomena” (DMP), which are events that caused significant damage to the  
494 national economy and vital activities of the population, report that seven years of the last  
495 decade (2006–2015) had the largest numbers of DMP (from 385 to 467). The impacts of these  
496 events often extend far beyond Northern Eurasia, sending aftershocks into global markets and  
497 raising concerns about global food security (Loboda et al. 2016).

498 There are also changes in the spatial and temporal distribution of inclement weather  
499 conditions (e.g., heavy wet snowfalls, freezing rains, rain on snow, untimely thaws and peak  
500 streamflow) that, while not being extremes *per se*, substantially affect societal well-being and

501 health (e.g., freezing events, Bulygina et al. 2015; Groisman et al. 2016) or indirectly impact  
502 the regional water budget (e.g., the influence of winter thaws and/or early snowmelt on the  
503 water deficit of the following growing season, Bulygina et al. 2009, 2011; Groisman and Soja  
504 2009). Societal consequences of changes in the frequency and intensity of these extreme and  
505 inclement events have become an urgent task to address for the entire Earth Science research  
506 community (Forbes et al. 2016). In this regard, it is not enough to report and/or to project  
507 changes in characteristics of these events but also to develop a suite of strategies for resilient  
508 responses to new climate conditions that are forthcoming and/or have an increased higher  
509 probability than was previously expected.

510       Extreme events that affect the biosphere and their temporal and spatial changes  
511 represent a special focus for NEFI studies. Wildland fire is the dominant disturbance agent in  
512 the boreal forests, which are in turn the largest global reservoir of terrestrial carbon (Pan et al.  
513 2011; Parham et al. 2014; Gauthier et al. 2015). While fire plays a critical role in maintaining  
514 the overall forest well-being through regulating ecosystem functioning, productivity, and  
515 health, extreme fire events and changing fire regimes intensify the impacts of climate change  
516 and variability on ecosystem states and deliver a suite of powerful feedbacks to the climate  
517 system. These events heighten the interactions among the biosphere, atmosphere, and climate  
518 systems by affecting carbon balances, hydrologic regimes, permafrost structure, modifying  
519 patterns of clouds and precipitation, and radiative forcing by changing surface and planetary  
520 albedo (Rogers et al. 2015). Wildfires, in general and particularly during extreme events, also  
521 have a direct adverse impact on human health, pose a considerable threat to life and property,  
522 and impose a substantial economic burden.

523       A typical feature of the current fire regime is increasing frequency and severity of  
524 mega-fires, defined as fires that involve high suppression costs, property losses, natural

525 resource damages, and loss of life (Williams 2013). These fires may cause the irreversible  
526 transformation of the forest environment for a period that exceeds the life cycle of major  
527 forest-forming species (Sukhinin 2010; Shvidenko et al. 2011; Figure 6). Mega-fires of the  
528 last decade have led up to a twofold increase in the share of crown and peat fires. Post-fire  
529 dieback in the area of mega-fires as a rule exceeds 50%. A substantial part of post-fire areas  
530 may become unsuitable for forest growth for hundreds of years. For instance, such areas in the  
531 Russian Far East (RFE) are estimated to cover tens of million hectares (Shvidenko et al.  
532 2013). The increasing aridity of the climate provokes outbreaks of harmful insects that could  
533 envelope large areas, for example, the outbreak of Siberian silk moth (*Dendrolimus superans*  
534 *sibiricus*) which enveloped an area of about  $10 \times 10^6$  ha in 2010. Human- and climate-induced  
535 change in disturbance regimes is currently acting in concert to force ecosystems to move more  
536 quickly towards a new equilibrium with the climate (van den Werf et al. 2010; Soja et al.  
537 2007).

538 **Figure 6.**

539 Severe fires, driven by anomalous weather conditions, are increasingly becoming the  
540 new norm across Russia. In the past 15 years, extreme fires have been reported across nearly  
541 all large geographic regions, including very remote zones (e.g. Yakutia in 2002) and densely  
542 populated regions (European Russia in 2010). Fire weather (temperature, precipitation,  
543 relative humidity and wind speed) in recent decades (2003–2012) is much more dangerous  
544 than in an earlier decade (1984–1993). In Figure 6, at the stages from b to i, forests might  
545 have the possibility to recover with (1) the absence of repeated disturbances; and (2)  
546 implementation of forest management mitigation efforts with increased resources for the most  
547 severe cases. However, if the recent tendencies of fire weather continue, the survival of the  
548 forest biome in its present boundaries is not possible (Tchebakova et al. 2009).

549 In 2008, smoke and related emissions from early season fires associated with  
550 agricultural/clearing in the country of Kazakhstan, in the Transbaikal region, and the Russian  
551 Amur Oblast (oblast is a large administrative division in Russia) were observed in the Arctic.  
552 On reaching the Arctic, this early season ash deposition could result in more rapid snow and  
553 ice melting, further altering albedo impacts on the ice sheet (Warneke et al. 2009). In 2010,  
554 the Moscow region experienced a record drought and the hottest summer in Russian recorded  
555 history (42°C), which resulted in extreme fires that burned in previously drained peatlands.  
556 This lethal combination of natural and human forcings resulted in monetary losses of  $3.6 \times$   
557  $10^9$  \$US (by other estimates up to  $10 \times 10^9$  \$US) and the death of nearly 56,000 people  
558 (Guha-Sapir 2010). In the spring of 2015, anomalous weather caused extensive and severe  
559 fires in Siberia that destroyed 1200 houses in 42 settlements and resulted in 36 deaths and  
560 hundreds of injuries in the Republic of Khakassia (Valendik et al. 2015). Similarly, fires in  
561 the Transbaikal region resulted in the loss of more than 240 houses in 18 settlements, the  
562 death of 11 people, and more than 30 people injured (Kukavskaya et al. 2016).

563 Wildfires are uncommon in Eastern Europe and European Russia (Krylov et al. 2014),  
564 but anthropogenic fires in agricultural areas, including croplands and pastures, are widespread  
565 (Soja et al. 2004; Dubinin et al. 2011; McCarty et al. 2017; Derevyagin 1987). Romanenkov  
566 et al. (2014) noted that a peak of satellite fire detections occurs in cropland areas in Russia,  
567 Baltic countries, Belarus, Ukraine, and Kazakhstan directly after the snow melt in the spring  
568 (indicating field preparation) and after agricultural harvests in the fall. Agricultural burning is  
569 a source of short-lived climate pollutants like black carbon (McCarty et al. 2012) and methane  
570 (McCarty et al. 2017). However, prescribed fire in forests, grasslands, or croplands is either  
571 illegal or not reported by national agencies in Lithuania, Belarus, or Russia (Narayan et al.  
572 2007). Efforts to organize reliable monitoring of such fires from space are warranted.

573

574 **Research focus 3: retreat of the cryosphere**

575 The cryosphere in the montane regions of Northern Eurasia is represented by three  
576 components: (i) seasonal and perennial snow pack; (ii) glaciers; and (iii) permafrost. The  
577 cryosphere retreat has a continent-wide spatial scale with temporal scales that vary from the  
578 century to millennia for glaciers and permafrost, to seasonal for snow cover extent  
579 (Shahgedanova et al. 2010, 2012, 2014; Aizen et al. 2007; Bulygina et al. 2011; Gutman and  
580 Reissell 2011; Sorg et al. 2012; Chen et al. 2013; Groisman and Gutman 2013; Nosenko et al.  
581 2013; Khromova et al. 2014; Blunden and Arndt 2015; Farinotti et al. 2015; Syromyatina et  
582 al. 2014, 2015; Fausto et al. 2016).

583 This retreat affects: a) continental energy balance changes due to decreases in surface  
584 albedo, increases in heat flux into the upper surface layers, and earlier spring onsets and  
585 longer growing seasons; b) the depletion of the continental water storage accumulated during  
586 the past millennia in ground ice with the subsequent desiccation of lands that rely upon water  
587 supply from glacial melt and permafrost thaw; and c) large-scale biosphere changes (Figure 4)  
588 especially prominent in regions where the cryosphere is intrinsically linked with the  
589 survival/dominance of major species within biomes (e.g., larch forest over the permafrost  
590 areas in northern Asia).

591 The most prominent snow cover changes are observed in the late spring (Figure 7a) while  
592 the total duration of seasonal snow on the ground is decreasing, there are days/periods, when  
593 snow maximum water equivalent and maximum snow depth have been increased over most of  
594 Russia (Bulygina et al. 2009, 2011, updated). Note that the strong systematic increase in  
595 spring temperatures in Northern Eurasia (Figure 3) was apparently enhanced by positive snow  
596 cover feedback.

597 **Figure 7.**

598 Changes in the extent and mass balance of glaciers are important primarily because of

599 their impact on water resources. Yet, while there is extensive information about glacier area  
600 change, less is known about changes in glacier volume and mass, either observed or projected.  
601 Within the domain of Northern Eurasia, assessments of changes of glacier mass on a regional  
602 scale are available for the Tien-Shan mountain system using Landsat and Corona satellite  
603 imagery which provided data on volume change (e.g., Pieczonka and Bolch 2015) and  
604 Gravity Recovery Satellite Experiment (GRACE) data (e.g., Farinotti et al. 2015). The latter  
605 provides data on changes in ice mass and is therefore directly relevant to the assessment of  
606 water resources. Yet for regions other than the Tien-Shan, the uncertainty of measurements  
607 using GRACE remains very high and often exceed the measured signal (Jacob et al. 2012). In  
608 other regions, changes in the mass and volume of ice are characterized using traditional  
609 glaciological surveyors' pole measurements of mass balance at the benchmark glaciers  
610 (World Glacier Monitoring Service 2015). Geodetic mass balance for smaller areas is based  
611 on using *in situ* geodetic measurements, aerial photography and high-resolution satellite  
612 imagery (e.g. Shahgedanova et al. 2012), and ground-penetrating radar (GPR) measurements  
613 performed both *in situ* and from the air (e.g. Kutuzov et al. 2015). This last method appears to  
614 be promising, particularly in combination with ice thickness modeling, e.g. the recently  
615 developed Glacier Base Topography Model, 2<sup>nd</sup> Version (GLABTOP2; Linsbauer et al.  
616 2012).

617 Within Northern Eurasia, the contemporary glaciation reaches its maximum extent in  
618 the mountains of Central Asia. In the Tien-Shan alone, according to different estimates,  
619 glaciers occupy between 15,400 km<sup>2</sup> and 16,400 km<sup>2</sup> (Sorg et al. 2012). The Altai Sayan  
620 Mountains and the Caucasus Mountains are other important centers of contemporary montane  
621 glaciation with a combined glacier area of approximately 1,550 km<sup>2</sup> (Aizen 2011) and 1350  
622 km<sup>2</sup> (Shahgedanova et al. 2014) respectively. Smaller centers of contemporary glaciation  
623 occur in the Polar Urals, mountains of eastern Siberia (e.g. Kodar, Chersky, and Suntar-

624 Kayata), and Kamchatka (Khromova et al. 2014). Across all these regions, with the exception  
625 of the coastal glaciers of Kamchatka (Khromova et al. 2014), glaciers are retreating although  
626 regional variations in retreat rates are observed both between and within the mountainous  
627 systems (Kutuzov and Shahgedanova 2009; Narama et al. 2010; Sorg et al. 2012;  
628 Shahgedanova et al. 2010). When observations allow, the retreat of glaciers can be  
629 documented at the century scale (cf., Figures 7c and 7d). In the first decade of the 21<sup>st</sup>  
630 century, the retreat rates increased to 1% yr<sup>-1</sup>, e.g., across most of Tien-Shan and Djungarskiy  
631 Alatau (Severskiy et al. 2016; Sorg et al. 2012; Farinotti et al. 2015; Pieczonka and Bolch  
632 2015). In addition to glaciers, the ongoing climate warming has already affected the ground  
633 ice of these mountain ecosystems (Jin et al. 2000, 2007; Marchenko et al. 2007; Wu et al.  
634 2013).

635 Across the Caucasus, the glaciated area has been shrinking at a slower rate of 0.4–0.5 %  
636 yr<sup>-1</sup> (Shahgedanova et al. 2014). Changes in the extent of glaciers of north-eastern Siberia and  
637 the Urals are often more difficult to quantify because of the small size and cloudy summer  
638 weather which make it difficult to obtain suitable satellite imagery. However, analysis of  
639 glacier change in the Kodar Mountains shows both a strong loss of glacier area, as high as 0.9  
640 % yr<sup>-1</sup> between the 1960s and 2010 (Stokes et al. 2013), and a strong loss of glacier volume  
641 and negative mass balance (Shahgedanova et al. 2011). Glaciers of the Polar Urals have lost  
642 nearly half of their area since the 1950s and exhibited negative mass balance (Shahgedanova  
643 et al. 2012).

644 It is difficult to believe that the temperature increases over montane areas of Central  
645 Asia and Caucasus will not affect the extent of the regional cryosphere unless there is a  
646 concurrent two-digit percentage increase in regional precipitation. Analyses of cyclonic  
647 activity over Central Asia do not show sizeable changes in the total cyclone numbers, and  
648 there are some increases in their variability. Furthermore, the number of deep cyclones,

649 which are already rare here, has decreased in the last decade (Figure 8). Thus, the countries  
650 comprising this region should be prepared to confront potential problems with water  
651 availability for montane agricultural fields and pastures.

652 **Figure 8.**

653 Permafrost and associated periglacial landforms can store large quantities of fresh  
654 water in the form of ice (30–70% by volume, Bolch and Marchenko 2009) to buffer the loss  
655 of glacial mass. The impact of a declining cryosphere on water resources varies among the  
656 regions. While the impact is predicted to be moderate in the northern Caucasus, which  
657 receives ample precipitation (Lambrecht et al. 2011), it is likely to be stronger in arid regions  
658 such as southern Caucasus and Central Asia. In particular, the mountains and plateaus of  
659 Central Asia have been in the spotlight of cryosphere research because they are a major  
660 regional source of fresh water for surface runoff, groundwater recharge, hydropower plants,  
661 community water supply, agriculture, urban industry, and wildlife habitat. Central Asia is  
662 categorized as a water-stressed area where projected climate change could further decrease  
663 streamflow and groundwater recharge (Core Writing Team 2007).

664 It is anticipated that under the current climate warming trend, the recession of glaciers  
665 in Central Asia will accelerate, leading to a temporary increase of runoff during the dry  
666 season. The studies of the observed and projected changes in discharge suggest that the peak  
667 flow might have already been reached and will continue for the next decade (Hagg et al. 2006,  
668 2013; Shahgedanova et al. 2016). However, on longer time-scales (> 50 years), the crucial dry  
669 season glacier runoff will be substantially reduced, as glaciers will lose most or all of their ice  
670 storage. In the same period, the melt of ground ice (initially trapped and accumulated in the  
671 permafrost) could become an increasingly important source of freshwater in the region.  
672 Currently few projections of future climate using regional climate modelling exist for Central  
673 Asia (Mannig et al. 2013; Shahgedanova et al. 2016). While all existing simulations project

674 an increase in air temperature for the region, there is substantial disagreement among the  
675 models on the future trends in precipitation.

676 In the last 30–40 years, observations have indicated a warming of permafrost in many  
677 northern regions with a resulting degradation of ice-rich and carbon-rich permafrost. Increases  
678 of permafrost temperatures observed in Northern Eurasia and North America have resulted in  
679 the thawing of permafrost in natural, undisturbed conditions in areas close to the southern  
680 boundary of the permafrost zone (Romanovsky et al. 2010a, 2017). Most of the permafrost  
681 observatories in Northern Eurasia show its substantial warming since the 1980s. The  
682 magnitude of warming has varied with location, but was typically from 0.5 to 3°C. In the  
683 regions where permafrost surface is already “warm” (i.e., where its temperature is close to the  
684 freezing point: Arctic shelf seas, riverbeds, edges of the present permafrost boundaries), such  
685 warming causes multiple changes in the terrestrial hydrological cycle, land cover, and man-  
686 made infrastructure (Pokrovsky et al. 2012; Shvidenko et al 2013; Shiklomanov et al. 2017).  
687 The close proximity of the exceptionally ice-rich soil horizons to the ground surface, which is  
688 typical for the arctic tundra biome, makes tundra surfaces extremely sensitive to the natural  
689 and human-made changes that resulted in the development of processes such as thermokarst,  
690 thermal erosion, and retrogressive thaw slumps that strongly affect the stability of ecosystems  
691 and infrastructure (see Research focus 7: changes in infrastructure). Figure 7b shows the  
692 number of newly emerging thermokarst lakes in West Siberia which indicate the rate of  
693 degradation there of the upper layer of the permafrost. A main aim of the future NEFI efforts  
694 related to permafrost is to evaluate its vulnerability under climate warming across the  
695 permafrost regions of the northern and high-elevation Eurasia with respect to ecosystems  
696 stability, infrastructure, and socioeconomic impact. A second aim is to estimate the volume of  
697 newly thawed soils, which could be a potential source or sink of an additional amount of  
698 carbon in the Earth system.

699        During the NEESPI studies of the past decade, the cryosphere retreat and its major  
700    manifestations were documented (Figure 7) and it was shown that this process plays a critical  
701    role in environmental changes across Northern Eurasia.

702

703    **Research focus 4: changes in the terrestrial water cycle**

704    The mountains of Northern Eurasia cut its landmass off from the major sources of water  
705    supply from the tropics. Even in the regions of “sufficient” moisture, this sufficiency is  
706    secured not by an abundance of water, but rather by suppressed evapotranspiration during the  
707    lengthy cold season, soil insulation from the atmosphere by seasonal snow cover, and by  
708    external water supply from cryospheric storage. The rest of the water is provided through  
709    unstable atmospheric circulation (e.g., cyclones). Changes caused by global warming can  
710    decrease and/or redistribute water supplies from the cryosphere, increase the vegetation  
711    period, and affect the water vapor transport from the oceans into the continental interiors  
712    where both absolute changes and variation in the water vapor transport are of great  
713    consequence. Both natural ecosystems and human activities rely upon the stability of the  
714    water supply. Looming changes include: (a) depletion of relatively stable water sources  
715    (cryosphere; Khromova et al. 2014), (b) an already unstable water source (atmospheric  
716    circulation) becoming even more variable (Schubert et al. 2014), and (c) a longer and warmer  
717    period for vegetation growth (“greening”) increasing the biospheric water demand (Park et al.  
718    2016). Given these, it becomes clear that changes in the terrestrial water cycle across  
719    Northern Eurasia can adversely affect the well-being of local societies as well as the world  
720    economy.

721    **Figure 9.**

722        There is ample evidence of changes in the terrestrial water cycle across Northern

723 Eurasia (AMAP 2011; Barros et al. 2014; Figure 9), including reduced snow cover (Brown  
724 and Robinson 2011; Callaghan et al. 2011a; AMAP 2011, 2017), intensifying spring melt  
725 (Bulygina et al. 2011), increasing river flow (Shiklomanov and Lammers 2009, 2013;  
726 Georgiadi et al. 2011, 2014a, 2014b; Georgiadi and Kashutina 2016; Holmes et al. 2015),  
727 disappearance of lakes (Smith et al. 2005; Shiklomanov et al. 2013) lengthened ice-free  
728 period in lakes and rivers (Shiklomanov and Lammers 2014), degradation of permafrost  
729 (Streletsckiy et al. 2015a), and melting of glaciers (Velicogna and Wahr 2013; Duethmann et  
730 al. 2015) among others.

731 River flow is a dynamic characteristic that integrates numerous environmental  
732 processes and aggregates their changes over large areas. River runoff plays a significant role  
733 in the fresh-water budget of the Arctic Ocean and its water supply especially during low flow  
734 seasons (fall-winter). Ocean salinity and sea ice formation are critically affected by river input  
735 (Rawlins et al. 2009). Changes in the fresh water flux to the Arctic Ocean can exert  
736 significant control over global ocean circulation by affecting the North Atlantic deep water  
737 formation with irreversible consequences for Northern Hemisphere climate (Peterson et al.  
738 2002; Rahmstorf 2002; Fichot et al. 2013). Eurasia contributes 74% of the total terrestrial  
739 runoff to the Arctic Ocean. The total annual discharge of six large Eurasian rivers increased  
740 from 1936 to 2010 by approximately 210 km<sup>3</sup> more than the annual discharge of the Yukon  
741 River (Shiklomanov and Lammers 2011), with a new historical maximum in 2007 (Figure 10;  
742 Shiklomanov and Lammers 2009; Holmes et al. 2015).

743 River discharge into the Arctic Ocean is a highly effective conveyor in transporting  
744 continental heat across Eurasia (Nghiem et al. 2014) under a warming climate with increasing  
745 temperatures (Figure 2). Eurasian rivers with immense watersheds, particularly the Severnaya  
746 Dvina, Pechora, Ob, Yenisei, Lena, and Kolyma Rivers, provide a massive flux of warm

747 waters into the Arctic Ocean or peripheral seas contributing to melt sea ice in spring and  
748 summer. The massive river energy flux to the Arctic Ocean carries an enormous heating  
749 power of  $1.0 \times 10^{19}$  J/yr for each  $1^{\circ}\text{C}$  of the warm river waters above freezing, which is  
750 equivalent to the power release from detonation of  $2.5 \times 10^9$  ton of trinitrotoluene (TNT) per  
751  $^{\circ}\text{C}$  per year (Nghiem et al. 2014). With increased water temperatures (Lammers et al. 2007)  
752 and longer ice-free periods of the Arctic rivers (Shiklomanov and Lammers 2014), the role of  
753 river heat input is increasing and must be incorporated in sea ice prediction and projection  
754 models. These changes of river discharge in Northern Eurasia have a predictive potential to  
755 force Arctic change at interannual to decadal timescales and beyond (Richter-Menge et al.  
756 2012).

757 **Figure 10.**

758 The Northern Eurasian freshwater cycle has been an important focus of ongoing  
759 research, and a great deal of work has been carried out to understand the increases in the river  
760 discharge to the Arctic Ocean and to identify whether or not the regional hydrological system  
761 is accelerating (e.g., Smith et al. 2007; White et al. 2007; Rawlins et al. 2010; Holmes et al.  
762 2013). Although a variety of theories have been put forward, the physical mechanisms  
763 driving the observed runoff changes are not yet fully understood. Comprehensive analyses of  
764 water balance components (Rawlins et al. 2005, 2010; Serreze et al. 2006; Shiklomanov et al.  
765 2007), human impacts (McClelland et al. 2004, 2006; Yang et al. 2004; Adam et al. 2007;  
766 Shiklomanov and Lammers 2009; Zhang et al. 2012a), and hydrological modeling  
767 experiments (Bowling and Lettenmaier 2010, Troy et al. 2012) have not revealed a clear  
768 cause of the observed increase in river discharge. Precipitation in the Eurasian pan-Arctic,  
769 which is the most important water balance component for the runoff generation, does not  
770 show a significant change to support the observed increasing trend in river flow (Adam and

771 Lettenmaier 2008; Groisman et al. 2014).

772 In contrast, the increase in air temperature across the pan-Arctic has been widely and  
773 consistently documented (Overland et al. 2014) and it is expected to continue with the higher  
774 rates in the future (Barros et al. 2014). The air temperature rise leads to significant changes in  
775 the regional cryosphere including spring snow cover retreat, less frozen soil in the winter  
776 season, deeper annual thaw propagation in the permafrost zone (deeper active layer) and  
777 melting of glaciers. Several local or regional studies have shown the important influence of  
778 changes in different cryospheric components including permafrost thaw (Davydov et al. 2008;  
779 Woo 2012; Streletskiy et al. 2015b), glacier melt (Bennett et al. 2015), less thickness of  
780 seasonally frozen soil (Markov 1994, 2003; Frauenfeld et al. 2004; Frauenfeld and Zhang  
781 2011; Shiklomanov et al. 2017), and river ice on river runoff generation (Gurevich 2009;  
782 Shiklomanov and Lammers 2014). However, it is not clear from these studies how these  
783 locally observed changes will interact among each other and with spatially varying  
784 precipitation changes to affect the river flow over the entire region and the freshwater flux to  
785 the ocean. There is also considerable uncertainty about how these local changes will scale up  
786 to regional and continental scale impacts.

787 Terrestrial evaporation and transpiration (evapotranspiration) are the components of  
788 the terrestrial hydrological cycle that are the most difficult to measure given few direct  
789 observations (Speranskaya 2011, 2016). Near-surface air temperatures are increasing, and  
790 one can expect that the evaporation from wet land surfaces should increase. However, the  
791 near-surface wind speeds over the entire territory of Russia have been decreasing in the past  
792 several decades (Bulygina et al. 2013 updated to 2016; such studies have not been completed  
793 for other parts of Northern Eurasia), and this may reduce the air-surface water vapor  
794 exchange. Furthermore, most Northern Eurasian land surfaces are not “wet” so a temperature

795 increase does not automatically induce an increase in evaporation. Opposite processes may  
796 prevail due to evaporation suppression by dry upper soil layer (Golubev et al. 2001). Thawing  
797 of permafrost and less seasonally frozen ground can significantly change underground  
798 hydrological pathways. This will lead to an increase in ground flow, higher runoff during the  
799 cold season and, correspondingly, to a decrease in total evapotranspiration. Finally, future  
800 ecosystem shifts can dramatically change the vegetation composition (Figure 4) and the  
801 transpiration rate of the new communities can induce further fundamental changes to the  
802 regional water cycle. All of the processes above suggest that changes in this component of the  
803 hydrological cycle are not trivial and should be assessed within new models that properly  
804 account for the interactions among the atmosphere, soil, and biosphere. Large-scale  
805 geochemical and geophysical runoff changes (biological and inorganic matter transports) also  
806 should be considered.

807 Recently, there were a number of assessments of trends in the discharge from  
808 glaciated catchments of Central Asia. A detailed review of changes in river discharge in the  
809 Tien-Shan has been provided by Unger-Shayesteh et al. (2013) who reported contrasting  
810 trends for its different sectors including increasing summer runoff in the northern and inner  
811 Tien-Shan, and decreasing summer runoff in the central and western Tien-Shan and at the  
812 lower elevations in the inner Tien-Shan. More recently, Shahgedanova et al. (2016) reported  
813 an increase in discharge from the glaciated catchments unaffected by human activities in the  
814 northern Tien-Shan using homogenized long-term records. Positive trends in the discharge  
815 from the headwater catchments of the Tarim River were reported by Duethmann et al. (2015),  
816 Krysanova et al. (2015), and Kundzewicz et al. (2015) who also attributed these changes  
817 primarily to the increasing glacier melt, but highlighted their inability to quantify water  
818 withdrawal and its contribution to the long-term trends as a limitation of these studies.

819 It is important to recognize that the increases in discharge due to glacier melt (if any)  
820 have been a temporary relief for water resources in the interior regions of Central Asia and  
821 Caucasus. In these regions, water stored in the cryosphere is limited and, if the current  
822 tendencies of the cryosphere depletion persist, they will result in severe water deficits in  
823 future decades. Therefore, it is time to begin preparations to mitigate and/or adapt to these  
824 deficits beforehand by developing management routines for water preservation and  
825 responsible consumption as well as by modifying agriculture and pastoral practices  
826 accordingly.

827 Accelerated climate- and anthropogenic-induced changes in the hydrological cycle  
828 raise societal concern because changes in the water level, streamflow, snow, ice, and frozen  
829 ground have pronounced effects on local and regional economies and the well-being of the  
830 Northern Eurasian residents. In particular, there may be immediate implications for water  
831 supply, irrigation, energy production, navigation, land and water transport, and structural  
832 engineering.

833 Presently, changes of the hydrological regime in Northern Eurasia are producing more  
834 and more freshwater input to the Arctic Ocean. The changes in river dscharge, along with the  
835 sea ice decline, and higher precipitation over the ocean may exert a significant control over  
836 the North Atlantic meridional overturning (thermohaline) circulation with potentially dramatic  
837 consequences for climate of the entire Northern Hemisphere. Accordingly, we should expand  
838 our knowledge to better understand these hydrological processes, to better project possible  
839 extreme events, and better adapt to ongoing and upcoming environmental changes.

840

841 **Research focus 5: changes in the biosphere**

842 Ecosystems in Northern Eurasia are subjected to the impacts of climate change and human  
843 activities over the entire sub-continent. In the northern part on sites with permafrost,

844 anthropogenic changes are primarily due to oil and gas exploration and extraction, mining,  
845 and infrastructure development. Further south, timber harvest (along with oil/gas) is  
846 predominant in the boreal and temperate forest zones, as are agricultural and pastoral  
847 activities in the forest-steppe and steppe zones. Industrial development often leads to the  
848 physical destruction of landscapes, changes of the hydrological regime, and widespread  
849 contamination of air, soil and water (Derome and Lukina 2011; Baklanov et al. 2013).  
850 Climate-induced changes in terrestrial ecosystems transform important ecosystems and their  
851 services, which in turn, require an adjustment in business planning, nature conservation, forest  
852 management, agricultural practices and regional economic policies to mitigate or adapt to  
853 these changes. The Siberian Taiga and Far East zones together comprise the largest part of the  
854 world's most intact remaining boreal forests (Potapov et al. 2008). It is now recognized that  
855 the RFE in particular is home to unique ecosystems and biodiversity (Newell and Wilson  
856 2004).

857 In the long term, terrestrial ecosystems function in a dynamic balance with the states  
858 of climate, water resources, the lithosphere, and cryosphere. When these four driving forces  
859 change, ecological systems also begin to change. Currently, significant changes in forest area  
860 and composition are predicted to occur within a few future decades (see Figure 4 and  
861 discussion). Ongoing climate change already impacts the ecosystems of Northern Eurasia and  
862 may provide hints for projecting future changes. These impacts are manifold and relate to  
863 diverse features of ecosystem states and behavior like health, productivity, resilience, change  
864 of natural disturbance regimes, major biogeochemical cycles, among many others (Kharuk et  
865 al. 2017b).

866 Forests disturbed within the last 30 years account for approximately  $75 \times 10^6$  ha (9%)  
867 of Russian forests (Loboda and Chen 2016). Dendrochronological data show that fire  
868 frequency has been increasing in different parts of Russia throughout the 20th century

(Voronin and Shubkin 2007; Kharuk et al. 2016). Recent satellite-based assessments show that the rates of forest disturbance have increased further since 2000 compared to the pre-2000 era across all forest biomes with the largest increase from  $1.2$  to  $2.2 \times 10^6$  ha year $^{-1}$  in Eastern Siberia associated with an increase in fire occurrence (Loboda and Chen 2016). The average extent of burnt area during the last 15 years over Russia is estimated at  $10\text{--}13 \times 10^6$  ha year $^{-1}$  with the post-fire forest mortality rate of  $1.76 \times 10^6$  ha year $^{-1}$  (Krylov et al. 2014; Bartalev et al. 2015). In the future, the frequency and extent of a fire occurrence in boreal forests are expected to rise further under the projected scenarios of climate change by anywhere from 25–50% (Flannigan et al. 2000, 2013) to 300–400% (Shvidenko and Schepaschenko 2013; Abbot et al. 2016) with an accompanying 50% increase in fire weather severity. These, in turn, are likely to result in large scale ecosystem shifts. For example, an increase in fire frequency is expected to lead to the disappearance of the pure Siberian pine stands in southern Siberia and the replacement of Siberian pine forests by Scots pine stands in the northern regions (Sedykh 2014). Repeated disturbances have resulted in substantial decreases in fuel loads and led to soil erosion, overheating, the absence of nearby seed sources, and the proliferation of tall grasses. As a result, the lack of natural post-fire regeneration of forests has led to their conversion to steppe vegetation (Kukavskaya et al. 2016; Figure 6). Based on the analysis of satellite vegetative indices combined with ground-based data, repeated fires have been found to have the most negative impact on reforestation, forcing the failure of post-fire regeneration in more than 10% of the forested area in the south-western part of the Transbaikal region (Shvetsov et al. 2016). Furthermore, Flannigan et al. (2013) project that cumulative fire severity would increase three times and fire season length could increase by 20 days by 2091 for Northern Eurasia. Thus, there is an urgent need for planning adaptive forestry and fire management activities designed specifically for the regions that take into account trends in conditions and local features (climatic, forest-vegetation,

894 social, technical, and economic).

895        While productivity of forests at the continental level has increased during the last few  
896 decades at a rate of 0.2–0.3% per year due to increasing temperature and lengthening of the  
897 growth period, there are large territories with decreasing productivity (Schaphoff et al. 2015)  
898 and enhanced mortality of trees. This mirrors the general condition for the entire boreal belt  
899 (Allen et al. 2010). The forests over large territories in different regions of Northern Eurasia  
900 are exposed to substantial dryness, particularly those which are dominated by dark coniferous  
901 tree species (Shvidenko et al. 2013) resulting in increased water stress and impacts of forest  
902 pests and pathogens. Increasing climate aridity has caused the morphological structure of  
903 forests to change (Lapenit et al. 2005). High variability of climate and an increase in the  
904 frequency and severity of long dry and hot periods (heat waves) impact forest health and the  
905 productivity of ecosystems in a visibly negative way (Bastos et al. 2014; Gauthier et al. 2015).  
906 Impacts of seasonal weather on net primary production and soil heterotrophic respiration is  
907 ecosystem/soil type and bioclimatic zone specific (Shvidenko and Schepaschenko 2014;  
908 Mukhortova et al. 2015).

909        Influences of climate changes on vegetation are primarily manifested in the alteration  
910 of the basic biogeochemical functions — first of all, the exchange rates of water vapor and  
911 carbon dioxide between plant ecosystems and the atmosphere. When ecosystems respond to  
912 changes in ambient temperature and moisture conditions, the direct response can be quite  
913 rapid. For example, an increased frequency and duration of droughts result in a  
914 transformation of the functional role of wetlands to be a source rather than a sink of CO<sub>2</sub> for  
915 the atmosphere (Bohn et al. 2013; Olchev et al. 2013a, 2013b).

916        Sustainability of the forest carbon sink under changing climate is a serious concern,  
917 given the huge task of limiting the growth of atmospheric greenhouse gases (GHG)  
918 concentrations to levels adopted under the Paris Agreement of 2015

919 (http://ec.europa.eu/clima/policies/international/negotiations/paris\_en). The global growth of  
920 CO<sub>2</sub> in the atmosphere is significantly compensated by the terrestrial biosphere sequestering 2  
921 to 4 Petagrams of carbon every year as evidenced globally from atmospheric composition  
922 measurements (Le Quéré et al. 2015). Atmospheric inverse models (Dolman et al. 2012)  
923 estimate the sink, which amounts to less than 4% of global net primary production, to be  
924 disproportionately allocated to high and mid latitudes of the Northern Hemisphere, including  
925 Northern Eurasia. This result is especially convincing when atmospheric observations over  
926 Northern Eurasia are used (Stephens et al. 2007; Maksyutov et al. 2013; Jiang et al. 2012,  
927 2016; Saeki et al. 2013). Terrestrial biosphere models and long-term atmospheric  
928 observations (Graven et al. 2013) reveal an increase of biospheric CO<sub>2</sub> seasonal exchange  
929 during the past few decades that are driven by rising temperatures and atmospheric CO<sub>2</sub>  
930 concentrations. Maintaining the size of the carbon sink in Northern Eurasia into the 21<sup>st</sup>  
931 century under the negative impacts of increased droughts and fires requires basically the same  
932 measures as those needed for sustaining forestry, namely fire protection and efficient forest  
933 management (Hurt et al. 2002, 2011; Shvidenko et al. 2013). Despite the high level of  
934 natural and human-induced disturbances, the ecosystems of Northern Eurasia currently serve  
935 as a net sink of carbon up to 0.5 – 0.6 Pg C yr<sup>-1</sup> (Dolman et al. 2012) with about 90% of this  
936 sink occurring in forested landscapes. However, Figure 11 shows that large areas of disturbed  
937 forests, basically on permafrost, have already become a carbon source.

938 **Figure 11.**

939 Current biosphere models predict diverse responses based on the acceleration of the  
940 carbon cycle by future climate change. A significant change is expected for ecosystems on  
941 permafrost, but many important features of ecosystems at high latitudes are not adequately  
942 incorporated in these models. For the permafrost-region in Russia, current estimates indicate  
943 that the end-of-the-century release of organic carbon from the Arctic rivers and collapsing

944 coastlines may increase by 75% (Gustafsson et al. 2011). The carbon loss from wildfires may  
945 increase substantially (Shvidenko et al. 2013). The expected changes of ecosystems in  
946 permafrost regions include forest decline over large regions from changes in the hydrological  
947 regime and increasing water stress (Figure 4). Still, it is not clear whether northern forest  
948 ecosystems will reach a tipping point, but this is very likely under regional warming above  
949 7°C (Gauthier et al. 2015; Schaphoff et al. 2015). The uncertainty of such a prediction is  
950 high. However, it is very likely that the permafrost region will become a carbon source to the  
951 atmosphere by the end of this century, regardless of which warming scenario is used.  
952 Purposeful forest management could substantially slow down this process (Abbot et al. 2016).

953 Logging is an important disturbance factor in many forest areas of Northern Eurasia  
954 (Achard et al. 2006; Gauthier et al. 2015). Logged sites are usually highly susceptible to fire  
955 due to a combination of high fuel loads in leftover debris and accessibility for human-caused  
956 ignition (Loboda and Csiszar 2007; Loboda et al. 2012). These sites typically experience  
957 higher severity fires than do unlogged forests, and these fires can spread to adjacent areas  
958 (Ivanov et al. 2011; Kukavskaya et al. 2013a). In the dry lands, clear-cut logging accelerates  
959 the conversion from forest or forest-steppe to steppe vegetation.

960 Throughout the Taiga zone, timber harvesting (Bergen et al. 2008) and possibly  
961 human-exacerbated forest fires (Kasischke et al. 1999) are major contributors to change in the  
962 ecological systems of Northern Eurasia. Forest harvest in Russia as a whole, and in particular  
963 in Siberia and the RFE has changed over the past fifty years with high harvest rates  
964 characterizing the late Soviet era (Peterson et al. 2009). After the dissolution of the former  
965 Soviet Union, these rates dropped to less than  $100 \times 10^6 \text{ m}^3$  (Bergen et al. 2008) although  
966 more recently they have partially rebounded. The early Soviet era saw an emphasis on  
967 harvest from western Russia. Since the 1980s, the greater development of logging in Siberia  
968 and the RFE was spurred by declining western Russia reserves, incentives to establish

969 industry in the eastern reaches of Russia and agreements with Japan (in 1968 and 1974) for  
970 forestry infrastructure development in Siberia/RFE. Most recently (and in the foreseeable  
971 future), trade in eastern regions is influenced by increasing demand from China (Figure 12),  
972 with significant potential to adversely impact the health and intactness of Siberian and RFE  
973 forests in particular (Bergen et al 2013; Newell and Simeone 2014).

974 **Figure 12.**

975 Predictions of the future distribution and state of ecosystems in Northern Eurasia vary  
976 considerably (Gustafson et al. 2011a, 2011b; Tchebakova and Parfenova 2012, 2013), with  
977 remaining large uncertainties in the vegetation dynamics. Progress in dynamic vegetation  
978 observations and modelling in North Eurasia has become more visible with the recent  
979 availability of high-resolution remote sensing data on topography, plant phenology, biomass,  
980 and soil wetness (Kharuk et al. 2017a; Tchebakova et al. 2016a, 2016b). However, more  
981 efforts will be needed to expand the new data capabilities into lowlands and tundra regions.

982 Study results from the region suggest that further global warming will put at risk the  
983 sustainability of forest and forest landscapes (Gauthier et al. 2015; Schaphoff et al. 2015;  
984 Figure 4). As mentioned earlier in this paper, models predict substantial shifts of vegetation  
985 to the north with forest steppe and steppe expected to be dominant across large southern  
986 territories of the present forest zone (Schaphoff et al. 2006; Tchebakova and Parfenova 2012).  
987 However, the changes in climatic conditions during the last several decades have occurred too  
988 rapidly for vegetation structure to completely adjust to the new conditions. The immediate  
989 response of vegetation cover to changes of climatic variables can be quite rapid, but the  
990 recovery can be characterized to occur over a longer time frame with significant delay. When  
991 the climate changes shift a region to conditions outside of the range of dominant species, the  
992 past and current seed dispersal rates (Udra 1988) are slower than the migration rate needed for  
993 vegetation to alter its composition to one appropriate to the predicted climate change.

994           A similar conclusion was reached based on comparisons of palynological data and  
995   radio-carbon dating in Western Europe (Huntley and Birks 1983) and in the European part of  
996   Russia (Velichko 2002; Velichko et al. 2004). It has been shown that under warming during  
997   the first half of the Holocene, the expansion rate of the majority of tree species was 200 - 300  
998   m per year although the rate did reach 500 – 1000 m per year for pioneer species (birch and  
999   aspen). Similar estimates of the expansion rate of the boreal and temperate tree species in the  
1000   early Holocene (from 100 to 1000 m per year) have been obtained from palynological data  
1001   (Higgins and Richardson 1999; Tinner and Lotter 2001; Higgins and Harte 2006).

1002           The results of paleoclimatic and paleogeographical reconstructions of the past epochs  
1003   can be useful (as analogues) for prediction of the possible changes of the vegetation cover due  
1004   to the projected change of climate conditions in the 21<sup>st</sup> century. Numerous refugia (areas  
1005   with species that are different from the surrounding dominant ecosystems/populations)  
1006   provide clues to the boundaries of the past ecosystems and also show the level of their  
1007   resilience to a changing environment. Many global and regional paleoclimatic reconstructions  
1008   have been compiled for various warming and cooling periods of the Late Pleistocene and  
1009   Holocene (Velichko 2002). According to available paleogeographical data, the thermal  
1010   maximum of the Holocene (about 6–5.5 ka BP) could be considered as an analogue of the  
1011   climatic conditions for the middle of the 21<sup>st</sup> century and the optimum of the last Interglacial  
1012   (Mikulino-Eemian-Sangamon, Stage 5e of the deep-sea oxygen curve, about 125 ka BP)  
1013   period could be considered as a paleo analogue for the end of the 21<sup>st</sup> century (Velichko et al.  
1014   2004). Still it is not clear how much dispersal rates may accelerate under climate change, but  
1015   it is very likely that the southern parts of the forest zone will be under very high risk, and the  
1016   potential loss or decline of southern taiga forests will not be compensated for by increasing  
1017   forest area beyond the current northern tree line.

1018           Ecosystem changes in the present forest zone of Northern Eurasia may be quite rapid

1019 due to simultaneous effects of climate change that is among the largest over the planet (Figure  
1020 3; Blunden and Arndt 2015, 2016) and of anthropogenic factors such as logging (Figure 12),  
1021 air, soil, and water pollution, and man-induced fires (see Research focus: frequency and  
1022 intensity of extremes). First of all, the feedbacks from these changes directly affect the  
1023 ecosystem services to societies of the region and, thus, their well-being. Secondly, the  
1024 biogeochemical feedbacks of the carbon cycle changes in the forest and tundra zones of  
1025 Northern Eurasia and its Arctic shelf seas may go far beyond the continent after the release of  
1026 methane and CO<sub>2</sub> from large carbon storage in forest, wetlands, and frozen soil to the  
1027 atmosphere due to biomass decomposition, fires, and thawing (Friedlingstein et al. 2006;  
1028 Shvidenko et al. 2011, 2013; Gao et al. 2013; Gauthier et al. 2015; Shakhova et al. 2015;  
1029 Ruppel and Kessler 2017). These types of feedbacks affect the rates of global Earth system  
1030 change and, therefore, represent a global concern.

1031 In Central Europe, air pollution has been recognized as a key threat for forest  
1032 ecosystems since the second half of the 20<sup>th</sup> century. At the end of the 20<sup>th</sup> century, sulphur  
1033 and nitrogen depositions in Europe connected with lignite combustion and the high  
1034 concentration of industry reached their highest levels. Thereafter, the deposition of S  
1035 decreased by >80% (Schöpp et al. 2003), with concurrent reductions in NH<sub>3</sub> and NO<sub>x</sub>  
1036 (Kopáček and Posh 2011). The decrease of SO<sub>2</sub> emissions in Czechia has been one of the  
1037 most pronounced (Vestreng et al. 2007), and is believed to have profound consequences for  
1038 ecosystem biogeochemistry (Oulehle et al. 2011). This reduction in pollution has to be  
1039 continued and its monitoring remains an important task.

1040 Norway spruce (*Picea abies*) is a tree species sensitive to air pollution. Thus, Norway  
1041 spruce forests in the mountains of Central and Eastern Europe have been selected for regional  
1042 studies of the interaction of climate and socio-economic drivers (Campbell et al. 2004;  
1043 Mišurec et al. 2016; Kopačková et al. 2014, 2015). Since 1994, a network of 15 small

1044 forested watersheds (GEOMON) was established in Czechia to understand the forest response  
1045 to air pollution. Since then, GEOMON has provided a testbed for exploration of element  
1046 cycling on a watershed scale using modern remote and proximal sensing methods (Fottová  
1047 1995; Oulehle et al. 2008).

1048

1049 **Research focus 6: pressure on agriculture and pastoral production**

1050 The temperate and steppe zones of East Europe are a breadbasket for a large part of Northern  
1051 Eurasia (Swinnen et al. 2017). However, under pressure of growing population, the nations of  
1052 these zones will need to invest in climate-smart agricultural techniques to sustain or continue  
1053 to improve agricultural yields and livestock production given forecasted climate change.  
1054 “Climate-smart” agricultural systems are resilient to climate change and offer carbon and  
1055 GHG emissions mitigation potential without compromising productivity, food security, and  
1056 the livelihoods of those working in the agricultural sector. So far, Iizumi and Ramankutty  
1057 (2016) found that statistically significant increases in wheat yields in Ukraine were explained  
1058 by improved agro-climatic conditions, i.e., warmer and longer growing seasons, and not by  
1059 management strategies.

1060

1061 *Land abandonment and recultivation*

1062 During the past quarter-century, land abandonment in the Northern Eurasia region has  
1063 been associated with fundamental changes in agricultural production and land use caused by  
1064 the breakup of the Soviet Union in 1991 (Lerman et al. 2004). The guaranteed markets and  
1065 subsidized production from the Soviet era, particularly in the livestock sector and less  
1066 productive agricultural land, were lost. This caused an unprecedented drop in fodder-crop  
1067 production, plummeting livestock numbers (Schierhorn et al. 2014a), decline in grain yields  
1068 (Trueblood and Arnade 2001), increased fallow periods (de Beurs and Ioffe 2014) and

1069 widespread agricultural land abandonment (Alcantara et al. 2012, 2013; Prishchepov et al.  
1070 2012; Griffiths et al. 2013; Lieskovský et al. 2015). According to official statistics,  
1071 approximately, 59 Mha of farmland were abandoned from 1991 to 2000 across the post-  
1072 Soviet countries (Figure 13). A large portion of this change occurred in Russia. Two  
1073 generalized trajectories of change resulted from this perturbation of 1991 and its subsequent  
1074 effects up to the present: 1) some former agriculture lands have been taken out of production  
1075 and have become reforested, and 2) others were temporarily taken out of production but have  
1076 been later recultivated and/or otherwise put back into production under different ownership,  
1077 management or other socio-economic processes.

1078 With regards to the first trajectory, overall, the abandoned agricultural fields in  
1079 Eastern Europe and Russia are driving an increase of forest cover, and have become a  
1080 terrestrial carbon sink at the global scale over the late 20th and early 21st centuries  
1081 (Kuemmerle et al. 2011b; Schierhorn et al. 2013; Kurganova et al. 2014, 2015). By 2010,  
1082 approximately 5 Mha of new forests were observed on former agricultural fields in Eastern  
1083 Europe that were cultivated during the Soviet era (Potapov et al. 2015). In the temperate zone,  
1084 abandoned fields are often slowly but steadily encroached by shrubs and forests. Varying  
1085 levels and timing of abandonment of agricultural lands were observed at the landscape level  
1086 in three Landsat scene case study sites over the period 1975–2001 in the Siberian Taiga zone  
1087 (Bergen et al. 2008), with most consistent decreases in agricultural land areas after 1990.

1088 After the dissolution of the Soviet Union and subsequent cessation of the state  
1089 subsidies for collective agriculture, large areas of less productive croplands were either  
1090 abandoned (Alcantara et al. 2012, 2013; Prishchepov et al. 2012) or the fallow periods  
1091 increased (de Beurs and Ioffe 2014). Potapov et al. (2015) reported that 32% of total forest  
1092 regrowth between 1985 and 2012 was due to afforestation of former agricultural lands.  
1093 However, afforestation of abandoned croplands is currently not included in the official

1094 forestry reports (Potapov et al. 2012), and the legal status of these lands remains uncertain.

1095 **Figure 13.**

1096 The second trajectory which centers on land recultivation is more complex. First,  
1097 agriculture abandonment rates varied across all of the former-USSR countries and were  
1098 mediated by national and regional policies regarding support of agriculture (Prishchepov et al.  
1099 2012), as well as access to new markets (de Beurs and Ioffe 2014). One of the lowest rates of  
1100 abandonment was observed where land reforms were successfully completed in a short period  
1101 (Poland) or, in an alternate case, where they were absent (Belarus). Strong regional  
1102 differences were also observed within countries. For example, Ioffe et al. (2012) looked at  
1103 the contrasting situation of Kostroma, an oblast in the north of European Russia and Samara,  
1104 an oblast in southern European Russia. In the northern oblast, agriculture is now limited and  
1105 in retreat beyond relatively small-scale operations in suburbia, while in Samara, the  
1106 agricultural activity now appears to be sustainable, albeit on a somewhat less extensive spatial  
1107 scale than in the past.

1108 After 2000, a partial recultivation of abandoned lands has been observed, which is  
1109 primarily driven by adjustment of agricultural policies and growing prices for agricultural  
1110 commodities (de Beurs and Ioffe 2014; Estel et al. 2015; Meyfroidt et al. 2016; Smaliychuk et  
1111 al. 2016). However, recultivation rates have been compensated by ongoing agricultural land  
1112 abandonment—reaching 60 Mha by 2013 for three largest post-Soviet agricultural nations  
1113 (Figure 13). From 2000 to 2010, grain yields increased (Trueblood and Arnade 2001; Liefert  
1114 et al. 2010). In southern Russia where the physical attributes, location, and human resources  
1115 are best positioned to support agricultural activity (e.g., in Stavropol' Krai), there is growth  
1116 potential for agriculture (Kattsov et al. 2012). Here there is evolving specialization of former  
1117 socialized farms in response to market conditions. In Stavropol', this involves a shrinkage of

1118 animal husbandry and a consequent release of surplus labor, increased levels of absentee  
1119 (corporate) ownership of farmland in the more favorable locations, decoupling of the  
1120 economic fate of successful large farms from deficient local municipal budgets, and an  
1121 expansion of non-Russian ethnic communities in the countryside (Ioffe et al. 2014).

1122 Dynamics of cultural landscapes in European countries of the former Soviet Bloc can  
1123 also be characterized by two opposite processes – intensification and extensification (Fjellstad  
1124 and Dramstad 1999; Bičík et al. 2015). Intensification occurs when cropping intensity or  
1125 livestock stocking increases on some land. This may be accompanied by abandonment of  
1126 other, more marginal cropland, pastures, or rangeland. In contrast, extensification occurs  
1127 when more cropland or pastures are needed so that additional natural lands are converted to  
1128 agriculture. Land abandonment in Central and Eastern Europe since the 1950s has resulted  
1129 from a complex multi-dimensional process with environmental, ecological, economic and  
1130 social consequences (Kuemmerle et al. 2008; Keenleyside and Tucker 2010). Detailed  
1131 information about abandoned lands is missing from European national land resource statistics.

1132 The combined abandonment-reforestation and abandonment-recultivation trajectories  
1133 potentially provide future options for both biofuel production and cropland expansion. The  
1134 Northern Eurasian region represents a great potential to boost agricultural production  
1135 (Schierhorn et al. 2014b), and also to provide other ecosystem services on abandoned lands.  
1136 However, climate change and socio-economic and political development may substantially  
1137 limit such opportunities (Meyfroidt et al. 2016). The future of some abandoned lands is  
1138 uncertain due to the fluctuation of prices for agricultural commodities, growing interest in  
1139 biofuel production and development of national food security programs by the successors of  
1140 the former Soviet Union. In some post-Soviet countries (e.g., Ukraine), land reforms are not  
1141 yet completed to this date (2017), limiting recultivation of abandoned lands. Adverse

1142 demographic conditions in Eastern Europe associated with an exodus of the rural population  
1143 (Nikodemus et al. 2005; Prishchepov et al. 2013) and the depopulation of rural areas in China  
1144 (Liu et al. 2010) may trigger additional land abandonment. Because of limited institutional  
1145 and economic ability to adapt to changing weather patterns, the increase of weather extremes  
1146 represents a real threat for future agricultural production in Northern Eurasia. This may  
1147 reduce the possibility to close existing yield gaps (Dronin and Kirilenko 2010; Lioubimtseva  
1148 and Henebry 2012; Schierhorn et al. 2014a; Horion et al. 2016). Last but not least, the  
1149 observed increases in cropping intensity (de Beurs and Ioffe 2014) without adequate  
1150 application of fertilizers may reduce soil fertility and diminish yields.

1151 With respect to the above, the importance of socio-economic factors in land use is  
1152 paramount. For example, the level of institutional suppression in two major crop-producing  
1153 nations of the former Soviet Union, Ukraine and Russia, during the last 60 years of the Soviet  
1154 period was so high, that the former Soviet Union imported grain in the last two decades of its  
1155 history. Conversely, in recent years, even after the massive land abandonment in the 1990s,  
1156 these two nations have become the second and third major wheat exporters globally.

1157

1158 *Agriculture and pastoral production in the DLB*

1159 Spanning 25–125° E and 24–55° N across 17 countries (Figure 1), the DLB is the largest  
1160 contiguous dryland in the extratropics. The region has served as the historical trade route  
1161 between the Chinese East and the Mediterranean West, combining the Persian Royal Road  
1162 and the Silk Road. The Silk Road was and is an important international trade route between  
1163 China and the Mediterranean. Historically, the Silk Road has experienced major expansions  
1164 and geopolitical conflicts among cultures and religions, political and institutional shifts  
1165 including the collapse of the Soviet Union (Hostert et al. 2011). Especially in the last

1166 millennium, resource extractions (e.g., oil), rapid land use change (e.g., urban and agricultural  
1167 expansion), climatic change, and natural disturbances (e.g., dust storms) have driven change  
1168 in the region. The increased demand for meat and dairy products have produced strong  
1169 pressure on agro-pastoral lands where transitional economies with frequent institutional shifts,  
1170 water resource scarcity and climate conditions interact to alter DLB ecosystems and societies.  
1171 The geopolitical systems are diverse, but most countries in the region are either developing or  
1172 transitional economies with great demands for meat and dairy production (Ojima and Chuluun  
1173 2008)

1174 While climate projection models agree that the DLB will become much warmer over  
1175 the rest of the century, there is little agreement and considerable uncertainty about future  
1176 precipitation patterns for the region. The Fifth IPCC Assessment Report (AR5; IPCC 2014)  
1177 stated with high confidence that the Coupled Model Intercomparison Project Phase 5  
1178 (CMIP5) generation of models could project temperature distribution at a regional scale better  
1179 than the previous generation of models. However, the AR5 report states with “a medium  
1180 confidence” that there had been no improvements in model performance for precipitation.  
1181 Moreover, global and regional climate models are seriously challenged by the rugged terrain  
1182 found in much of the DLB (Parfenova et al. 2013; Lu et al. 2009a; John et al. 2013b, 2016).

1183 Over the past three decades, the DLB has gone through several major changes that  
1184 drive regional agricultural and pastoral land changes. First, the regional population has  
1185 increased at a moderate rate similar to the global population trend. But some areas, especially  
1186 around urban agglomerations in the East Asian part of the DLB, have increased more rapidly  
1187 resulting in greater pressure on agricultural and pastoral lands (Qi et al. 2012a, 2012b;  
1188 Kraemer et al. 2015). Second, there have been profound institutional shifts in the agricultural  
1189 sector, primarily in post-Soviet Central Asia where the newly independent states have  
1190 disparate natural resource endowments. To balance food security with commodities for

1191 export, these new nations have shifted their agricultural priorities (for example, replaced high  
1192 water demanding cotton by wheat) that have altered regional water demands — resulting in  
1193 agricultural abandonment in some locations and intensification in others (Wright et al. 2012;  
1194 de Beurs et al. 2015; Kraemer et al. 2015).

1195 Observations and biosphere models suggest that climate change is producing shifts of  
1196 the ecotones in the drylands of Asia (Groisman and Soja 2009; Tchebakova et al. 2016a). The  
1197 northward movement of the tree line and the changing dynamics of cover types, such as  
1198 shrublands and savannas in the grassland matrix, alters feedbacks to carbon, water, and  
1199 energy balances. Warming trends along with land-use and land-cover change (LULCC) could  
1200 substantially modify the carbon balance and biodiversity of the Eurasian Steppe. Natural and  
1201 anthropogenic factors act in concert amplifying one another. Consequences of reckless land  
1202 use and general drying of the continental interiors include water scarcity, lowered water  
1203 quality, soil salinization from agriculture intensification, and the disappearance of lakes/rivers  
1204 due to reduced snow packs, glacier loss, and aggressive fresh water extraction (Klein et al.  
1205 2012).

1206 The region has also experienced a rapid transformation in land cover. Grasslands have  
1207 been converted to croplands in Central Asia and in portions of East Asia. Changes from  
1208 cropland to vacant land have accompanied the collapse of the Soviet Union as farms were  
1209 abandoned *en masse* (Lioubimtseva and Henebry 2009; Chen et al. 2015b; Figure 13). The  
1210 net gain in carbon sequestration due to abandonment of croplands is offset by grassland  
1211 degradation from the increased grazing pressures following dramatic increases in land  
1212 privatization (e.g., herding policy on the Mongolia Plateau, Chen et al. 2015b), and increased  
1213 food demands (Qi et al. 2012b).

1214 **Figure 14.**

1215 LULCC has simultaneously occurred at an alarming scale across the DLB. A

1216 transition matrix based on the Moderate Resolution Imaging Spectroradiometer (MODIS)  
1217 Land Cover Type Product (MCD12Q1) between 2001 and 2012 revealed that shrublands and  
1218 savannas (i.e., steppe) show a high degree of turnover across the entire region, at 38% for  
1219 shrublands and 73% for savannas, respectively (Figure 14). Regionally, shrublands and  
1220 savannas showed a greater turnover (77% and 89%, respectively) during the decade, with East  
1221 Asian and Central Asia at 47% and 88%, respectively, and the Middle East at 39% and 54%,  
1222 respectively. Similarly, croplands and cropland/natural vegetation mosaics have high  
1223 turnover in East Asia (53% and 72%, respectively), in Central Asia (49% and 66%,  
1224 respectively), and in the Middle East (25% and 73%, respectively). Barren and water cover  
1225 types represent about 35% and 1% of total land area, respectively, but showed a 15% and  
1226 18% turnover across the region, respectively. Intensive use of exposed barren areas has  
1227 escalated dust storms, drought severity, and water shortages (e.g., Xuan et al. 2000; Chen and  
1228 Liu 2014). Worse yet, in the Fifth IPCC Report, Barros et al. (2014) predicts that this water-  
1229 limited region will experience a warming trend significantly higher than the global mean,  
1230 which would alter summer and winter precipitation patterns and increase the frequency of  
1231 extreme climate events with longer, more intense, and more frequent summer heat waves.  
1232 Cook et al. (2016) reports that, since 1998, the drought in the eastern Mediterranean Levant  
1233 region (Cyprus, Israel, Jordan, Lebanon, Palestine, Syria, and Turkey) is the worst drought of  
1234 the past nine centuries. Furthermore, the LULCC in DLB is expected to be significantly  
1235 higher in the upcoming decades than now (Kelley et al. 2015; Chen et al. 2017), jeopardizing  
1236 the regional stability and sustainability of the DLB. All of these factors along with its  
1237 landlocked geographic location make DLB a hotspot for the scientific community concerned  
1238 with negative consequences of ongoing global change.

1239 By shifting C stocks in soils and vegetation, both abandonment and intensification  
1240 strongly impact the regional carbon budget. For instance, the total extra C sink in abandoned

1241 croplands in Kazakhstan (12.9 Mha) over 1991-2010 is estimated to be nearly  $31 \pm 2$  Mt C yr<sup>-1</sup>,  
1242 which could compensate annually for about 49% of the current fossil fuel emissions in this  
1243 country (Kurganova et al. 2015). Most countries within the DLB implemented various reform  
1244 policies to promote economic growth while improving quality of life. The new governance  
1245 and policies increased GDPs, but at the same time resulted in shifting food demands, moving  
1246 towards more processed, high protein animal products, which can drive increases in  
1247 grasslands-based livestock production (Chen et al. 2015a, 2015b).

1248 A regional land-use change analysis using MODIS data suggests differential land-use  
1249 change across the DLB (Figure 15) with cropland abandonment in the west (zoom windows at  
1250 the bottom) and expansion in the east (zoom windows at right) are driven primarily by shifts  
1251 in governance and economic development. Therefore, the DLB has seen increasing demands  
1252 for food quantity and quality as well as decreasing food production, resulting in unbalanced  
1253 pressure on agricultural and pastoral lands (Chen et al. 2015a, 2015b).

1254 **Figure 15.**

1255 From the perspective of cultural and social norms, the Asian part of DLB shares  
1256 similarities in history of nomadic herding lifestyles and in geographic proximity. Totaling  
1257 8.82 million km<sup>2</sup>, Central Asia, Mongolia and Northern China includes the largest land-  
1258 locked countries (Kazakhstan and Mongolia) and has been influenced by some of the most  
1259 severe geopolitical, biophysical, and socioeconomic disturbances affecting societies and  
1260 simultaneously their livestock, a major source of food in the region. The region's total  
1261 livestock of 209.16 million animals in 1992 increased to 278.3 million in 2011 (33.1%  
1262 increase). However, livestock in Kazakhstan and Kyrgyzstan decreased substantially (by  
1263 43.8% and 34.1%, respectively) likely due to the collapse of the Soviet Union. Empirical  
1264 relationships among ecosystem production, population density, gross domestic production,  
1265 and land use remain intrinsically connected even with major policy shifts (such as the collapse

1266 of the Soviet Union or the new status of China within the World Trade Organization (Chen et  
1267 al. 2015a, 2015b). The underlying mechanisms responsible for these consistent relationships,  
1268 as well as their dynamics remain unknown.

1269 Food security in the Central Asian part of the DLB critically depends on the water  
1270 availability from the mountains, especially given the drying, browning, and brightening trends  
1271 that characterize the region during the past 15 years (de Beurs et al. 2015). Some countries  
1272 started taking practical measures by constructing reservoirs in order to ensure their economic  
1273 development. These actions will have short-term benefits, but estimates of contemporary and  
1274 future water resources that will originate from the high mountain cryosphere at the regional  
1275 scale are needed to develop long-term adaptation and mitigation strategies. These estimates  
1276 will be used for socio-economic vulnerability assessments of the benefits to local  
1277 communities whose livelihood depend on the quantity and seasonality of water discharges  
1278 from the Central Asian mountains with respect to regional and national priorities. This  
1279 specific objective will require the blending of geosciences with social sciences to evaluate the  
1280 role of high-elevation ice storage in permafrost and glaciers for levels of vulnerability and the  
1281 resilience of mountain and downstream ecosystems along with their inhabitants.

1282

### 1283 **Research Focus 7: changes in infrastructure**

1284 In the previous sections we mostly describe environmental and climatic changes in Northern  
1285 Eurasia in recent decades. They have affected infrastructure of the region. In particular, the  
1286 Arctic and Siberia have been substantially affected by the permafrost changes and its impact  
1287 on man-made infrastructure (e.g., buildings, factories, mines, bridges, roadways, and  
1288 pipelines). In the boreal zone, gradual onset of drier climate conditions accompanied with  
1289 more frequent wild fires endangers human settlements, silviculture, and agriculture. In the  
1290 DLB, a general depletion of already scarce water resources affects the general well-being of

1291 all population groups, and all aspects of human activity. These climate-related impacts on the  
1292 infrastructure have been compounded by the marked social, economic, and institutional  
1293 changes over Northern Eurasia during the past three decades. Therefore, this section is  
1294 devoted mostly to the socio-economic changes attributable to the dramatic political and  
1295 economic transformations that have affected infrastructures of Northern Eurasia.

1296 In Russia, these transformations have been most pronounced in its Arctic regions  
1297 where regional welfare critically depends upon the well-being of the entire country (e.g.,  
1298 Stammler 2005; Forbes et al. 2009; Kumpula et al. 2011; Pelyasov 2011; Hitztaler and Bergen  
1299 2013; Andrew 2014). Here, several socio-economic processes are major anthropogenic  
1300 drivers of environmental change since the 1960s. These include migration, urbanization, and  
1301 industrialization (e.g., Heleniak 2010, 2014). Ongoing and projected climate-induced changes  
1302 in natural systems will impact the human environment with direct, immediate implications for  
1303 land use, the economy, subsistence, and social life.

1304 Although some climatic changes may be economically beneficial (e.g., decrease in  
1305 climate severity and associated heating costs, longer navigation season), other changes  
1306 negatively impact the natural environment, both traditional and nontraditional sectors of the  
1307 economy, and the regional socioeconomic conditions. Overall, these climatic-induced  
1308 changes in natural conditions exert additional pressure on the marginal environments of  
1309 Eurasian Arctic, which are already stressed by human activities (Fondahl 1996; Crate 2006;  
1310 Forbes et al. 2009). For example, infrastructure development and climate change are  
1311 interacting in complex ways to alter permafrost over large areas of the Eurasian Arctic (Shur  
1312 and Goering 2009; Polishchuk and Polishchuk 2013, 2014). Communities, urban  
1313 environments, and industrial infrastructure built on ice-rich soils can be catastrophically  
1314 affected by thawing permafrost (Streletskev et al. 2012; Shiklomanov and Streletskev 2013;

1315 Shiklomanov et al. 2017). Simultaneously, permafrost thawing, caused by both climate and  
1316 infrastructure changes, affects natural landscapes and ecosystems (Raynolds et al. 2014;  
1317 Khustalev and Davidova 2007; Khustalev et al. 2011).

1318 Permafrost thawing and its associated impacts on natural and built environments have  
1319 been identified as priority issues for all Arctic regions (Walker and Pierce 2015). Due to  
1320 unprecedented levels of urban and industrial development, this problem is most pronounced  
1321 for the Arctic regions of Northern Eurasia.

1322 The Taiga ecoregion of Northern Eurasia has also seen dramatic pendulum-like shifts  
1323 in population, infrastructure and forest resource use between the late Soviet, early post-Soviet,  
1324 and the present-day eras. Over this time span, additional changes in the ecosystems driven by  
1325 climate factors have also been accompanied by multiple severe wildfire years. Siberia's  
1326 population expanded by 9 million people (23.5 to 32.5 million) between the years 1959 to  
1327 1989; a similar trend occurred in the RFE. This was due in large part to state incentives  
1328 encouraging settlement of these eastern reaches of the Soviet domain. Thus in these  
1329 'peripheral' regions away from the 'center' (Moscow and St. Petersburg), population growth  
1330 was strongly a product of in-migration and not intrinsic population growth.

1331 With the relatively sudden withdrawal of State-supported programs, this situation  
1332 precipitated significant shifts in population and natural resource use in the immediate post-  
1333 Soviet era (Voinova et al 1993; Bergen et al. 2013). Driven by significant economic hardship,  
1334 subsequent population out-migration began ~1990, which pervaded East Siberia and the RFE  
1335 and has only recently been lessening. In addition to high rates of migration out of the regions  
1336 altogether, residents also migrated within the regions from rural areas to the few main cities,  
1337 resulting in a more urban population.

1338 During the final three decades of the Soviet era, the forestry sector sustained high rates

1339 of timber production in Siberia. Some of this timber was exported to Japan based on official  
1340 agreements with Japan in 1958 and 1974 (Mathieson 1979) and, in the last decades, to China  
1341 (Figure 12). This brought investments in infrastructure. Despite the otherwise successful  
1342 commitment of the Federal Forest Service to scientific forestry including the creation of forest  
1343 inventory and an exceptional scientific knowledge (Kukuev et al. 1997), late Soviet-era forest  
1344 harvest itself was surprisingly inefficient (Shvidenko and Nilsson 1994). Immediately after  
1345 political dissolution in 1991, total harvest volumes significantly declined across Russia to  
1346 approximately 175 million m<sup>3</sup> compared to approximately 400 m<sup>3</sup> in 1989 (Bergen et al.  
1347 2013). Significant growth did not occur again in the forest industry until approximately 2009.

1348 As governance and institutions have regrouped after the early post-Soviet transition  
1349 era, new or renewed developments in forest and energy sectors have emerged. Resource use  
1350 in the taiga of Siberia and the RFE is influenced by its proximity to China, Japan and Korea.  
1351 These countries have (a) some of the world's highest human population density numbers, (b)  
1352 either naturally limited or depleted forest resources, and (c) far-reaching global-industrial and  
1353 trade conglomerates (Crowley 2005; Bergen et al. 2013). Thus, in Russia, the geographic  
1354 location of forest exploitation is shifting to eastern reaches that can easily supply and  
1355 transport logs to the growing Asian market (Newell and Simeone 2014). This occurs both  
1356 through legal forest management and harvest but also through illegal harvest (Vanderghert and  
1357 Newell 2003).

1358 Siberia and the RFE Taiga regions are also rich in oil, gas and minerals, i.e., natural  
1359 resources which are of great current economic and strategic importance. Within Russia there  
1360 may be a greater shift in oil and gas extraction to East Siberia and the RFE given that the  
1361 historic large oil reserves of western Siberia are thought to be approximately 75% tapped  
1362 (Dienes 2004). The Eastern Siberia-Pacific Ocean pipeline has recently been completed,  
1363 along with a spur directly into northern China. Most significantly, Russia sees its energy

1364 sector as a strategic central pillar to its re-establishment as a global economic power (Dienes  
1365 2004; Hashim 2010). Thus, it is likely that energy extraction and associated infrastructure  
1366 will increase.

1367 Communities in the Asian part of DLB are poised between dry and cold weather  
1368 conditions. Their position is precarious in the face of multiple forces: climatic variations,  
1369 extremes, and their changes; environmental degradation and loss of ecosystem services;  
1370 globalization of markets; rapid population growth and changes to demographic structure; out-  
1371 migration of the young and able segments of society with the subsequent brain drain and  
1372 remittances to the left-behind families. Rural dryland communities in Central and East Asia  
1373 face further challenges and opportunities due to the lingering consequences of the institutional  
1374 upheaval and uncertainty following the end of the Soviet Union, China's market reforms and  
1375 increasing regional influence of China. The DLB region has a low population, but the  
1376 population is rapidly increasing. The total population in Central Asia and Mongolia in 1992  
1377 was 54.05 million. In 2011, it increased to 67.09 million, a 24.1% increase over the 20 year  
1378 period. As might be expected, this population increase is coupled with rapid urbanization,  
1379 agricultural development, and desertification (caused by heavy grazing) across Central and  
1380 East Asia. The average regional increase of urban population from 1992 to 2011 was 27.3%  
1381 with the largest increases occurring in China and Tajikistan (both of ~50%) and the lowest  
1382 increase occurring in Kazakhstan (6.4%). In contrast, there is a 10.1% decrease in urban  
1383 population in Mongolia.

1384 Along with drastic changes in economics, institution and governance, land use in the  
1385 dryland Asia region includes the improvements of major infrastructures, which have  
1386 facilitated the transition of these nations. An obvious example is the region-wide installation  
1387 of mobile communication facilities enabling information exchanges for effective and efficient  
1388 communications. A second major infrastructure improvement is the development of

1389 transportation networks including aviation, railways, and highways across the region that  
1390 enabled more efficient logistics management and distribution of goods within countries as  
1391 well as trade across countries.

1392 **Figure 16.**

1393 A crucial infrastructure factor in these DLB regions is a rapid rate of urbanization  
1394 (Koch and Valiyev 2015). In particular, real estate development in the decade of the 2000s  
1395 has led to major lateral expansion as well as vertical build-up that have transformed small  
1396 cities into major metropolises. For example, in Kazakhstan, the extent of the Almaty urban  
1397 agglomeration has increased substantially as observed by the Dense Sampling Method (DSM)  
1398 (Nghiem et al. 2009) using NASA satellite scatterometer data in 2000–2009 (Figure 16).  
1399 With the capability to track urban change in three dimensions (Nghiem and Small 2016),  
1400 DSM results also reveal the significant vertical build-up as observed in the Almaty urban core  
1401 area with a fast growth rate of approximately 7% per year in terms of the total volume of  
1402 building structures in the 2000s (Figure 17). Such an overheated urbanization rate may result  
1403 in an excessive building supply that surpasses the building occupancy rate, and thereby may  
1404 turn the real estate boom into a bust.

1405 In northern China, tremendous urban development quadrupled Beijing urban extent  
1406 observed by DSM in the 2000s and brought along severe air pollution as a consequence  
1407 (Jacobson et al. 2015). Similarly, in the DLB cities such as the complex of Xiangfang,  
1408 Nangang, and Harbin have experienced multi-fold lateral expansion and significant vertical  
1409 build up shrouded in smog due to soaring air pollution from coal combustion and the  
1410 petrochemical industry (Huang et al. 2016). Mongolia has also undergone rapid urbanization  
1411 similar to that of many cities in northern China, resulting in serious air pollution problems  
1412 caused by automobiles and industrialization (Batmunkh et al. 2013). In any case, the rapid

1413 urban transformation exerts a high demand for rapid infrastructure development, such as road  
1414 networks not only for intra-urban but also for inter-urban connectivity to support the  
1415 commercial and industrial activities for the increasing population.

1416 **Figure 17.**

1417 Complex interactions among a rapidly changing climate and the continuously evolving  
1418 social, economic, and political systems in Northern Eurasia require an integrative approach  
1419 for studying the cumulative effects of infrastructure and climate change on high-latitude  
1420 social-economic and natural systems. This research should focus on assessing the  
1421 vulnerability of communities, industries, and ecosystems and should aim at developing  
1422 adaptation and mitigation strategies and plans for the sustainable development of the Arctic  
1423 infrastructure. The high latitudes of Eurasia, the largest and most dynamically complex  
1424 northern region, can serve as a basis for developing effective climate mitigation policies and  
1425 adaptation measures for global circumpolar North. The observed disparity of changes among  
1426 the DLB countries hints that the socioeconomic factors define the resilience of these countries  
1427 to ongoing changes and not so much the climatic factors.

1428

1429 **Research focus 8: societal feedbacks in response to environmental changes**

1430 In the distant past, humans reacted to environmental changes passively – they migrated away  
1431 from environments that became adverse or unsustainable. Nowadays, many societies are  
1432 equipped with tools and resources to withstand the negative consequences of environment  
1433 change, to some extent. Common approaches to addressing adverse environmental changes  
1434 include irrigation, construction of dams and dikes, diversion of water streams, large-scale geo-  
1435 engineering projects (e.g., reforestation), mandatory ecological standards to curb pollution,  
1436 more effective agronomic practices and robust crops, new construction codes, and the  
1437 application of ecological expertise to each new large development.

1438 **Figure 18.**

1439 Planning is also now beginning to be practiced to reduce the adverse impact of  
1440 disasters associated with environmental changes and increase the resilience of the  
1441 communities at risk. Implementation of these activities has associated costs and requires  
1442 careful planning based upon numerical experiments with models that realistically describe  
1443 processes of environmental changes in all their complexity and interactions. It should also  
1444 consider disruptive effects of environmental hazards given the uncertainty of the future  
1445 environment state and the trend of increasing frequency of loss events and damage produced  
1446 by disasters and creeping environmental crises globally (Figure 18) and also regionally  
1447 (Porfiriev 2001, 2016). The need for a suite of such models is more urgent when the risks of  
1448 negative consequences of environmental change are higher (Porfiriev 2012, 2013, 2014).

1449 Human activities have been the drivers of certain ongoing environmental changes. It is  
1450 important to recognize the loop: societal feedbacks in response to these changes may facilitate  
1451 the recurrence of disasters or cause a second cycle of inadvertent environmental change if the  
1452 response misses the target or is ill-designed. For instance, reforestation may cause more  
1453 intense rainfall and dykes may increase flood peaks. Curbing industrial development may  
1454 negatively impact human well-being and overall societal resilience. This means that studies  
1455 of the impact of environmental changes on societies and the development of adaptation and  
1456 mitigation measures in response to their detrimental consequences should be accompanied by  
1457 thorough assessments of the “end state” resulting from the environmental changes and the  
1458 actual and projected societal response to these changes. This can be implemented only by  
1459 mainstreaming all these kinds of impacts and feedbacks into comprehensive Earth System and  
1460 integrated assessment models (see the next section of this Paper).

1461

1462 **Research focus 9: quantification of the role of Northern Eurasia in the global Earth and**  
1463 **socioeconomic system**

1464 Northern Eurasia is a key part of the global Earth and socioeconomic systems. It occupies a  
1465 substantial portion of the land surface of the Earth (19%) and 60% of land surface north of  
1466 40°N. Northern Eurasia is where some of the largest climatic, environmental, and socio-  
1467 economic changes have occurred during the past century. In many aspects, changes here  
1468 presage the rates of global change including global temperature rise (cf., Figure 3 versus  
1469 Figure 2). The strength of the snow cover-temperature biogeophysical feedback,  
1470 biogeochemical feedback due to depletion of the surface and upper soil layer carbon and  
1471 frozen ice storages (Figure 7; Romanovsky et al. 2010a, 2010b; Schepaschenko et al. 2013;  
1472 Shakhova et al. 2015), atmospheric dust load from extensive DLB desert areas (Lioubimtseva  
1473 and Henebry 2009, Sokolik 2013; Sokolik et al. 2013), and atmospheric pollution from  
1474 industrial development (Lu et al. 2010) and from boreal forest fires (Soja et al. 2007) affect  
1475 the global climate and environment. Large areas of natural and anthropogenic land-cover  
1476 change are closely related to the interaction of the cryosphere and terrestrial hydrology change  
1477 (Tchebakova et al. 2009; Zhang et al. 2011, Mátyás and Sun 2014; Figure 4) with human  
1478 activities (Qi et al. 2012a, 2012b; Chen et al. 2013, 2015a; Horion et al. 2016, Figures 12 and  
1479 15). The importance of these changes and associated impacts on Northern Eurasia and  
1480 potential feedbacks to the global Earth and socioeconomic systems may be quantified using  
1481 models.

1482

1483 **Global change modeling for Northern Eurasia**

1484

1485 As discussed in the previous sections, Northern Eurasia is comprised of a complex and

1486 diverse set of physical, ecological, climatic and human regional systems, which interact  
1487 among themselves and can have potentially important feedbacks on the evolution of the  
1488 global Earth and human systems. At the same time, the region has experienced dramatic  
1489 climate, environmental and socio-economic changes, which leads us to argue that studying the  
1490 fate of Northern Eurasia needs to be placed in the context of global change modeling (i.e. the  
1491 modeling of the coupled human and Earth systems at the global scale) and include  
1492 interactions with other regions of the globe. In this section, we review past and ongoing  
1493 modeling studies over Northern Eurasia and provide new approaches for integrated modeling  
1494 for Northern Eurasia.

1495

#### 1496 **Past and ongoing modeling studies over Northern Eurasia**

1497 Many models have been developed and used to study various components of the Earth system  
1498 with a focus on Northern Eurasia. Monier et al. (2017) provides an overview of recent and  
1499 ongoing modeling studies over Northern Eurasia and identifies the many ecological and  
1500 geophysical processes comprising Earth system dynamics (i.e. the hydrological cycle, soil  
1501 thermal dynamics, wildfires, dust emissions, carbon cycle, terrestrial ecosystem dynamics,  
1502 climate and weather, sea ice) and the human dimensions (i.e. demography, risk management  
1503 addressed, agriculture, forestry, water management) addressed by the Northern Eurasia  
1504 modeling community. Because of the major role of Northern Eurasia in the global land  
1505 system, they find that most studies focus on the land processes (i.e. land and water carbon  
1506 cycle, energy balance) or on the fate of the land system under climate change (permafrost  
1507 thawing, agriculture, wildfire). They also find that most studies focus on a single component  
1508 of the Earth system, with generally little attention placed on interactions and feedbacks, and  
1509 with climate change being imposed. Nonetheless, Monier et al. (2017) identify a few studies

1510 that try to integrate various aspects of the Earth system, in terms of scale, teleconnection or  
1511 global feedbacks, and processes, as well as other studies focusing on integrated systems where  
1512 multiple disciplines overlap, such as modeling studies of water management (Shiklomanov et  
1513 al. 2013) or land management (Gustafson et al. 2011a, 2011b; Kuemmerle et al. 2011a,  
1514 2011b, 2014; Lebed et al. 2012; Loboda et al. 2012; Robinson et al. 2013; Shuman et al.  
1515 2013a; Blyakharchuk et al. 2014). This growing effort to integrate existing models through  
1516 scale, processes and feedback has translated into more coordinated and multidisciplinary  
1517 research projects by NEESPI scientists along with the development and integration of models  
1518 that can interact with each other, including weather and aerosol physics, permafrost and  
1519 terrestrial hydrology with water management, the carbon and water cycles, land carbon and  
1520 atmospheric transport modeling, and biospheric and climate information (Table 1).

1521 **Table 1.**

1522 Modeling studies focusing on a specific component of the Earth system have provided  
1523 valuable insight into processes controlling their behavior and the direct impact of climate  
1524 change. Meanwhile more integrated modeling studies have been useful for identifying and  
1525 quantifying potential interactions and feedbacks among various components of the Earth  
1526 system and societal activities associated with environmental changes over Northern Eurasia.  
1527 However, most studies of climate change impacts rely on standard socio-economic and  
1528 climate change scenarios, thus limiting the possibility of conducting integrated studies. A  
1529 common experimental design for these studies is to prescribe climate change and to examine  
1530 the varied response of a particular component of the Earth system (Rosenzweig et al. 2014).  
1531 In such an approach, many potential global and regional feedbacks that can have major  
1532 implications for the climate system, both in Northern Eurasia and globally, are overlooked.  
1533 The development of effective climate mitigation and adaptation strategies for Northern

1534 Eurasia depends on understanding how environmental conditions may evolve in the region  
1535 within the context of global change, including the influence of feedbacks and potential  
1536 thresholds (i.e., “tipping points”). Fortunately, modeling frameworks have already been  
1537 developed to study these issues (see the next section) and they could be improved to better  
1538 represent the important aspects of the Earth system that are unique to Northern Eurasia.

1539

1540 **New approaches to integrated modeling for Northern Eurasia**

1541 Earth System Models (ESMs; Brovkin et al. 2006, 2013; Friedlingstein et al. 2006; Arora et  
1542 al. 2013; Eby et al. 2013; Zickfeld et al. 2013; Koven et al. 2015; Zaehle et al. 2015) have  
1543 been developed by coupling together unique Earth system component models (e.g.,  
1544 atmosphere, land, cryosphere, oceans). These provide an ideal modeling framework to  
1545 investigate interactions and feedbacks among these components as well as the impact of  
1546 changes in Northern Eurasia on the global Earth system. For example, in an ESM, carbon  
1547 emissions from land-use change in Northern Eurasia may increase atmospheric carbon  
1548 dioxide concentrations to influence climate, the uptake of atmospheric carbon dioxide by  
1549 oceans to influence ocean acidification, and the uptake of atmospheric carbon dioxide by land  
1550 vegetation in the future. ESMs provide tools to investigate the response of the system to  
1551 changes in external forcings that not only affect each of the components individually but also  
1552 the interactions among them. For example, climate change impacts cannot be examined  
1553 without considering the role of human activity. In current ESMs, however, there is a simple  
1554 representation of the influence of human activity on earth system components.  
1555 Anthropogenic effects related to industrial, residential, and agricultural activities may be  
1556 represented by simply prescribing an input of greenhouse gases into the atmosphere. More  
1557 sophisticated ESMs might also use prescribed changes in land use across the globe to simulate

1558 the effects of spatial and temporal variations in albedo, sensible and latent heat fluxes, and  
1559 greenhouse gas fluxes on regional and global energy budgets. In these ESM studies, the  
1560 simulated human activity is determined solely by prescribed policies without any  
1561 consideration about how feedbacks from changing environmental conditions might modify  
1562 these activities in the future. For example, the land-use change prescribed in CMIP5  
1563 simulations is driven solely by socio-economic considerations and does not account for  
1564 climate change impacts on land productivity (Hurtt et al. 2011).

1565 Because ecological and social systems are interdependent and constantly co-evolving,  
1566 their non-linear behavior is difficult to predict. Taking into account that human well-being  
1567 and ecosystem integrity are fundamentally linked, these processes must be managed in a way  
1568 that implies balancing economic capacity, environmental integrity, and resilience to future  
1569 changes (Jones et al. 2013; DeLucia 2015). For this reason, another major effort has been put  
1570 into the linkage between models of human activity, including the global economy, global  
1571 trade, demography, technologies and user preferences—which are essential to study the  
1572 potential impacts of humans on the environment—to models of the physical climate system,  
1573 generally simplified compared to ESMs. These models are known as **Integrated Assessment**  
1574 **Models** and allow economic decisions to respond to changing environmental conditions to  
1575 support mitigation and adaptation efforts (**IAMs**; Rotmans et al. 1990; Alcamo et al. 1994;  
1576 Weyant et al. 1996; Prinn et al 1999; Sokolov et al. 2005, 2009; van Vuuren et al. 2006, 2007;  
1577 Riahi et al. 2007; Hijioka et al. 2008; Melillo et al 2009, 2016; Wise et al. 2009; Reilly et al.  
1578 2012; Hallgren et al. 2013; Prinn 2013; Nelson et al. 2014a, 2014b; Sue Wing et al. 2015).

1579 IAMs have been at the core of the Representative Concentration Pathways (RCPs, van  
1580 Vuuren et al 2011), a set of socio-economic and emissions scenarios, including socio-  
1581 economic change, technological change, energy and land use, and emissions of greenhouse

1582 gases and air pollutants, developed for the climate modeling community in support of the  
1583 IPCC AR5.

1584 More recently, major efforts have focused on developing models with a detailed  
1585 representation of all components of the coupled Human-Earth system, by coupling IAMs with  
1586 ESMs, or essentially replacing the simplified representation of the climate system in IAMs  
1587 with ESMs. Such models can provide novel insights into the complex issue of global change  
1588 by accounting for an exhaustive number of feedbacks among the components of the Earth  
1589 system and of the human system.

1590 Figure 19 shows an example of a coupled human-Earth system model, with three  
1591 pathways for feedbacks between the two systems. The first pathway includes the human  
1592 activity model providing emissions of greenhouse gases, aerosols and other precursors of  
1593 atmospheric pollution, thus providing the footprint for both future climate change and air  
1594 quality, with a feedback on the human system through health impacts. The second pathway  
1595 centers on land, with the human activity model making decisions on land use change based on  
1596 natural ecosystem productivity and crop yield. Finally, the third pathway centers on water,  
1597 with the Earth system model computing basin-wide geophysical water resources and the  
1598 irrigation demand from crops, and the human system model making economically based  
1599 decisions on water availability for irrigation, with competition from municipal and energy  
1600 use. The global and regional climate would in turn be affected by land use and land cover  
1601 change and irrigation, through both emissions of greenhouse gases, changes in albedo and in  
1602 the hydrological cycle.

1603 **Figure 19.**

1604 At the frontier of integrated assessment modeling, a number of issues have emerged  
1605 that can be better examined with the ongoing development of coupled human-Earth system

1606 models for Northern Eurasia (Monier et al. 2017) and include the following:

- 1607 • The food-energy-water (FEW) nexus. While the FEW is a global issue and major efforts  
1608 are underway to improve its representation in models of the coupled human-Earth system,  
1609 it also has unique characteristics over Northern Eurasia that require specific improvements  
1610 for such models to be useful, including thermokarst dynamics, permafrost degradation,  
1611 scarcity of human infrastructure, varied levels of agricultural development and  
1612 management practices, locally diverse hydrological conditions associated with complex  
1613 biomes and climate interactions.
- 1614 • The air quality and health nexus. In addition to the traditional anthropogenic precursor  
1615 emissions associated with the industry, energy and transportation sectors, or biogenic  
1616 emissions of precursors, Northern Eurasia experiences varied and complex sources of air  
1617 pollution, including wildfires, crop residue burning and dust. Accounting for these  
1618 sources of pollutants, specific to Northern Eurasia, along with the transport of pollutants  
1619 to and from surrounding countries, to quantify the economic impact of future changes in  
1620 air pollution in the region can prove key to accurately inform policy responses for  
1621 Northern Eurasia.
- 1622 • The new transnationalism of natural resources. The more porous international borders  
1623 that have emerged after the dissolution of the former Soviet Bloc have considerable  
1624 implications for Northern Eurasia's natural resources. In particular, forest resources but  
1625 also oil and gas, are at the nexus of regional demand due to uneven distributions within  
1626 the countries of Northern Eurasia. Understanding and developing levels of sustainable use  
1627 will have implications ranging from local human livelihoods to the global carbon budget.  
1628 Integrated models will need to include local, regional and, now, even international drivers  
1629 and consequences of these coupled human-natural systems pertaining to natural resources.

1630 • The opening of new Arctic trade routes. New trade routes emerging as the result of the  
1631 shrinking of Arctic sea ice extent could result in the ability of the timber industry and  
1632 energy exploration to reach remote areas like Siberia. The development of infrastructures  
1633 to respond to these new economic opportunities, including potential population migration  
1634 within Northern Eurasia and from neighboring regions, will face challenges such as with  
1635 climate-driven permafrost degradation or the disappearance of temporary roads  
1636 constructed over frozen lakes and rivers. Investigating the fate of Northern Eurasia as  
1637 these new trade routes emerge will require a detailed regional coupled human-Earth  
1638 system model.

1639 As with any model activity, the representation of interactions and feedbacks among  
1640 Earth system components and societal activities in Northern Eurasia can be improved within  
1641 models, in order for these models to address such emerging issues. Insights gained from  
1642 previous and ongoing efforts by the NEESPI/NEFI research community, such as those on the  
1643 unique features and processes of Northern Eurasia described above, could be incorporated to  
1644 guide these model improvements to create a new generation of coupled human-Earth system  
1645 models to study the role of Northern Eurasia on global change. For example, most ESMs do  
1646 not have a representation of permafrost dynamics, which is important for Northern Eurasia as  
1647 the presence of permafrost affects the availability of soil moisture and the timing and  
1648 magnitude of runoff (which are important for the FEW nexus), the ability to support buildings  
1649 and other infrastructure (which is important for the socio-economic development of remote  
1650 regions in Siberia as Arctic trade routes open up after the sea ice retreat), and vegetation  
1651 primary production rates and decomposition rates of organic matter (which influence the  
1652 ability of the landscape to provide food, energy and timber and impact the timing, extent and  
1653 severity of wildfires, which in turn, impact air quality and health). In addition, the

1654 degradation of permafrost might also be associated with several important tipping points  
1655 including those related to water availability and the release of land carbon to the atmosphere.  
1656 The representation of permafrost dynamics in ESMs could strongly benefit from an improved  
1657 representation of soil thermal dynamics, as influenced by water, ice, organic matter and soil  
1658 texture in the soil profile, and of the surface insulating layer and its modification by snow  
1659 cover, moss, litter or wildfires. Furthermore, we suggest that to improve key processes  
1660 relevant to Northern Eurasia in ESM and IAM, like permafrost degradation, a stronger  
1661 involvement of the Northern Eurasia modeling community and local stakeholders is needed.

1662

## 1663 **Concluding comments**

1664

1665 The major goal of this paper is to introduce the reader to the present challenges in Northern  
1666 Eurasia and to outline the pathways forward to address these challenges in the coming  
1667 decades. In doing so, we have provided the reader with a sample of exemplars of NEESPI's  
1668 accomplishments. The science questions of the "*Northern Eurasia Future Initiative*" or NEFI  
1669 derive from an urgent need to incorporate and expand our knowledge of the consequences of  
1670 human and social dimensions in assessing current and future change in Northern Eurasia.  
1671 Across this region, the future strongly depends upon this incorporation and the amelioration  
1672 of environmental change, the effects of these changes on human societies, and bridging the  
1673 considerable gaps in research procedures, capacity for prediction, and in time- and space-  
1674 scales that complicate the integration of human dynamics with environmental dynamics.

1675 When the embryonic NEESPI project began over a decade ago, there were concerns  
1676 that a program spanning Eurasia involving scientists from multiple disciplines based in a

1677 score of nations with complex and sometimes opposing diplomatic missions could have been  
1678 a failure. However, there were several significant factors that brightened and opposed such a  
1679 dark forecast. Truly interdisciplinary interactions among engaged scientists who tackled a  
1680 shared problem are a remarkable glue for holding research projects together, and they proved  
1681 that creativity can prosper in “bottom-up” research programs. The role of Northern Eurasia as  
1682 a recipient and generator of planetary climatic change is an important “big question” that  
1683 captures the imagination of many scientists and transcends disciplines, cultures, languages  
1684 and national politics. It is also a challenge whose unraveling requires teams working together  
1685 openly in earnest and in good faith. The consequences of environmental and socio-economic  
1686 change in Northern Eurasia that may spread well beyond its boundaries have been simply too  
1687 dire to leave them unstudied and, generally speaking, unknown. NEESPI was born to reverse  
1688 the situation by elucidating both negative and beneficial aspects of these changes to inform  
1689 societies and, thus, better prepare them for resilient future development. An objective of  
1690 NEFI is that this development must now be secured by science-based strategies provided to  
1691 regional decision makers at different levels that will lead their societies to prosperity.

1692 Northern Eurasia has undergone significant environmental change, having experienced  
1693 warming in the past few decades that already exceeds the 1.5°C to 2.0°C warming limits  
1694 adopted as a target at the United Nations Climate Change Conference (30 November –12  
1695 December 2015, Paris, France). Several aspects of this warming are manifested in changes in  
1696 the regional energy and hydrological cycles, which affect and interact with the biosphere and  
1697 with socio-economic activities. These changes are multifaceted. Some of them seem and are  
1698 inevitable (e.g., ecosystems’ shift, glacial retreat and permafrost thawing, increased fire  
1699 regimes, the new state of the regional environment); however, it is imperative they are  
1700 acknowledged and comprehended. Some of these changes, particularly if their consequences  
1701 are adverse for human well-being, can be reversed, moderated or mitigated — hopefully to

1702 levels that will completely or substantially negate their undesirable impacts. These latter  
1703 instances include proactive and sometimes quite expensive interventions in water  
1704 management, forestry and agricultural practices, environmental protection, infrastructure and  
1705 urban planning and resource consumption. In any case, the scientist's duty is to propose and  
1706 justify strategies for resilient future development in the region. "To justify" is a key word  
1707 here. Scientists must strive to know the Earth system in its functional entirety to develop the  
1708 tools necessary to project the future state in response to natural and societal impacts, as well  
1709 as to estimate the overall consequences of the realization of these scenarios on human  
1710 wellbeing.

1711 To these ends, we have formulated three major science questions to be answered by NEFI:

1712 *1). How can we quantify and project ecosystems dynamics in Northern Eurasia when these  
1713 dynamics may be internally unstable, are controlled by components that have been  
1714 systematically changing, and have a potential to impact the global Earth system with  
1715 unprecedented rates of change over the next few decades?*

1716 *2). What are the major drivers of the ongoing and future changes in the water cycles of  
1717 Northern Eurasia and how will their changes affect regional ecosystems and societies, and  
1718 feedback to the Earth system and global economy?*

1719 *3). How can the sustainable development of societies of Northern Eurasia be secured in the  
1720 near future by overcoming the 'transitional' nature of their economics, environmental and  
1721 climatic change challenges, and by disentangling restrictive institutional legacies?*

1722 To address these science questions, nine research foci are identified and their selection  
1723 has been briefly justified in this paper. These research foci are: (1) Global change influence,  
1724 particularly warming in the Arctic; (2) Increasing frequency and intensity of extremes and

1725 changes in the spatial and temporal distributions of inclement weather conditions; (3) Retreat  
1726 of the cryosphere; (4) Changes in the terrestrial water cycle; (5) Changes in the biosphere; (6)  
1727 Pressures on agriculture and pastoral production; (7) Changes in infrastructure; (8) Societal  
1728 actions to mitigate the negative consequences of environmental change and to benefit from  
1729 the positive consequences; and (9) Quantification of the role of Northern Eurasia in the global  
1730 Earth and socioeconomic systems to advance research tools with an emphasis on observations  
1731 and models. The socio-economic research challenges are integral to and a top priority for  
1732 these research foci.

1733 Taking into account the numerous powerful feedbacks between the Earth and human  
1734 systems in Northern Eurasia, we propose to employ Integrated Assessment Models (IAMs) at  
1735 the final stage of this global change assessment. The purpose of these IAMs is to couple  
1736 Earth system component models with the result being a functioning integrated Earth System  
1737 Model. Simultaneously, models of the human system that represent the global economy,  
1738 global trade, demography, technologies and user preferences will be incorporated. These will  
1739 provide support to economic and societal decision-makers, so they are able to thoughtfully  
1740 respond to changing environmental conditions to support mitigation and adaptation efforts.  
1741 Development of IAMs which include detailed representation of all components of the Human-  
1742 Earth coupled system to account for the exhaustive number of feedbacks among these  
1743 components, is the overarching goal of NEFI global change research. These models will  
1744 provide information and guidance to decision makers in their efforts to secure sustainable and  
1745 prosperous societal development and resilience-based ecosystem stewardship in Northern  
1746 Eurasia.

1747 Finally, Northern Eurasia presents a range of complex human and environmental  
1748 systems varying from modern industrial societies to traditional indigenous cultures, all  
1749 undergoing significant social and environmental change. Certainly, the continuing

1750 transformation of the former USSR, China, Mongolia, and Eastern Europe represents one of  
1751 the largest and most profound social changes of recent decades. Through NEFI, the work in  
1752 Northern Eurasia is moving to more effectively address shared goals with interdisciplinary  
1753 programs at the global level. The research record that will stand as the basis from which to  
1754 launch NEFI is a logical consequence of the accomplishments of NEESPI. This situation and  
1755 the need for progress is critical. Now is the time to press forward with this opportunity. The  
1756 challenge lies before us.

1757

## 1758 **Abbreviations**

1759	ACIA	Arctic Climate Impact Assessment
1760	AMAP	Arctic Monitoring and Assessment Programme
1761	AR5	The Fifth IPCC Assessment Report
1762	BP	Before present
1763	CGCM3.1	Canadian Centre for Climate Modelling and Analysis
1764		Model, 3 <sup>rd</sup> Version
1765	CMIP5	Coupled Model Intercomparison Project Phase 5
1766	DLB	Dry Land Belt of Northern Eurasia
1767	DSM	Dense Sampling Method
1768	ERA-interim	Global atmospheric reanalysis developed at the European Centre
1769		for Medium-Range Weather Forecasts
1770	ESM	Earth System Model
1771	GCM	Global Climate Model
1772	GHG	greenhouse gases
1773	GLABTOP2	Glacier Base Topography Model, 2 <sup>nd</sup> Version

1774	GPR	ground-penetrating radar
1775	GRACE	Gravity Recovery Satellite Experiment
1776	GTN-P	Global Terrestrial Network for Permafrost
1777	GTOS	Global Terrestrial Observing System
1778	HadCM3	UK Hadley Centre Climate Model, 3 <sup>rd</sup> version
1779	IAM	Integrated Assessment Model
1780	ICSU	International Council for Science Union
1781	IPCC	Intergovernmental Panel on Climate Change
1782	IPCLCM4	Institute Pierre Simon Laplace Climate Model, 4 <sup>th</sup> Version
1783	LC/LU	Land Cover/Land Use
1784	LCLUC	Land Cover and Land Use Change
1785	MODIS	Moderate Resolution Imaging Spectroradiometer
1786	NEESPI	Northern Eurasia Earth Science Partnership Initiative
1787	NEFI	Northern Eurasia Future Initiative
1788	RFE	Russian Far East
1789	RubCliM	Large-Scale Bioclimatic Envelope Model
1790	SibCliM	Siberian Bioclimatic Model
1791	SIE	Sea Ice Extent
1792	WMO	World Meteorological Organization
1793		
1794	<b>Declarations</b>	
1795	The authors declare that they have no competing interest.	
1796		

1797 **Funding**

1798 Support for most of the US authors and contributors of this paper as well as the multiannual  
1799 support for the office of the NEESPI Project Scientist was provided by the NASA Land Cover  
1800 and Land Use Change (LCLUC) Program, in particular, by grants NNX13AC66G,  
1801 NNX11AB77G, NNX13AN58G, NNX15AD10G, NAG5-11084, 08-LCLUC08-2-0003,  
1802 NNX14AD88G, NNX08AW51G, NNX12AD34G, NNX14AD91G, and NNX15AP81G. The  
1803 research carried out at the Jet Propulsion Laboratory, California Institute of Technology, was  
1804 also supported by the NASA LCLUC Program. Support of NASA grants 08-TE08-029 and  
1805 NNH09ZDA001N-IDS for AS and NT are acknowledged. Research of MS is supported by  
1806 Newton-al-Farabi Fund (grant 172722855). Grant 14.B25.31.0026 of the Ministry of  
1807 Education and Science of the Russian Federation provided support to PG, SG, NT, AS, OB,  
1808 BP, and IP for their work conducted at the P.P. Shirshov Institute of Oceanology. The Project  
1809 "ARCTIC-ERA: ARCTIC climate change and its impact on Environment, infrastructures, and  
1810 Resource Availability" sponsored by: ANR (France), RFBR (Russia), and the US NSF (grants  
1811 1717770 and 1558389) in response to Belmont Forum Collaborative Research Action on  
1812 Arctic Observing and Research for Sustainability provided support for OZ, SG, BP, PG and  
1813 NS. A part of the paper is based on the research carried out with the financial support of the  
1814 Russian Foundation for Basic Research (Project No. 15-06-08163 "Assessment and forecast  
1815 of the socioeconomic and environmental implications of the climate change in the Arctic  
1816 region"). Support for AP is provided by the Russian Government Program of Competitive  
1817 Growth of Kazan Federal University (OpenLab Initiative). Support for JA is provided by  
1818 grant NPUIL01417 of the Ministry of Education, Youth and Sports of Czechia.

1819

1820 **Authors' contributions**

1821 PG, HS, GG, SM, and SG proposed the topic, conceived and designed this overview. They  
1822 wrote the Introduction part of the Manuscript. Other major contributors to the Introduction  
1823 Section are NS, ASo, and JQ. Major contributors to Section on Three Unique Features of  
1824 Northern Eurasia of Global Concern and Their Related Major Science Questions are PG, NT,  
1825 JQ, HS, NS, GH, KB, TL, AP, and DK. Each author of the paper has contributed to the Major  
1826 Research Foci Section of the paper. EM and DK are the major contributors to Section  
1827 devoted to Global Change Modeling in Northern Eurasia of the paper. HS and PG were the  
1828 major contributors to the last (Concluding Comments) Section. All authors read and  
1829 approved the final manuscript. All Authors suggested numerous editorial corrections to the  
1830 manuscript. In addition to scientific contributions, the language editorial service was  
1831 provided by the authors, who are the native English speakers: HS, DK, GH, KB, KdB, ASo,  
1832 and JM.

1833

1834 **Authors' information.** All authors and contributors of this paper are the Members of the  
1835 Northern Eurasia Earth Science Partnership Initiative (NEESPI) and the Northern Eurasia  
1836 Earth Science Partnership Initiative (<http://neespi.org>).

1837

1838 **Acknowledgements**

1839 All authors of this paper are also the Authors and the Members of the NEFI Science Plan  
1840 Preparation Team. Other Members of the NEFI Science Plan Preparation Team are:  
1841 Elena Parfenova, Russia; Daniel Brown, USA; Yizhao Chen, China; Alexander Georgiadi,  
1842 Russia; Vladimir Gershenson, Russia; Evgeny Gordov, Russia; Serguei Ivanov, Ukraine;  
1843 Martin Kappas, Germany; Julia Kurbatova, Russia; Richard Lawford, USA; Guoping Lei,

1844 China; Sergey Marchenko, USA; Alexander Olchev, Russia; Irina Danilovich, Belarus;  
1845 Vladimir Romanovsky, USA; Dmitry Schepaschenko, Austria; Andrei Sokolov, USA; Dmitry  
1846 Streletskiy, USA; Margarita Syromyatina, Russia; Natalia Tilinina, Russia; Xiaoping Xin,  
1847 China; Panmao Zhai, China; Tatiana Blyaharchuk, Russia; Lin Zhen, China. Special credit to  
1848 Alan Cantin, Canadian Forest Service, Natural Resources Canada, who prepared climate  
1849 change scenarios used in biosphere model simulations for Figure 4 of this paper and Deborah  
1850 Misch, Telesolv Consulting, USA for preparation of high quality figures of this paper.

1851

## 1852 **References**

1853 Abbot BW, Jones JB, Schuur EAG, Chapin III FS, Bowden WB, Bret-Harte MS, Epstein HE,  
1854 Flannigan MD, Harms TK, Hollingsworth TN, Mack MC, McGuire A, Natali SM, Rocha  
1855 AV, Tank SE, Turetsky MR, Vonk JE, Wickland KP, Aiken GR (2016) Biomass offsets  
1856 little or none of permafrost carbon release from soils, streams and wildfire: an expert  
1857 assessment. *Environ Res Lett* 11:034014 doi: 10.1088/1748-9326/11/3/034014.

1858 Achard F, Mollicone D, Stibig H-J, Aksenov D, Laestadius L, Li Z, Potapov P, Yaroshenko A  
1859 (2006) Areas of rapid forest-cover change in boreal Eurasia. *Forest Ecology and*  
1860 *Management*, 237:322–334. doi: 10.1016/j.foreco.2006.09.080.

1861 Adam JC, Lettenmaier DP (2008) Application of new precipitation and reconstructed  
1862 streamflow products to streamflow trend attribution in northern Eurasia, *J Clim*  
1863 21(8):1807–1828. doi:10.1175/2007JCLI1535.1.

1864 Adam JC, Haddeland I, Su F, Lettenmaier DP (2007) Simulation of reservoir influences on  
1865 annual and seasonal streamflow changes for the Lena, Yenisei, and Ob' rivers, *J Geophys*  
1866 *Res* 112:D24114. doi: 10.1029/2007JD008525.

1867 Aizen VB (2011) Altai-Sayan Glaciers. In: Singh VP, Singh P, Haritashya UK (eds)  
1868 Encyclopedia of Snow, Ice and Glaciers, Springer New York

1869 Aizen VB, Kuzmichenok VA, Surazakov AB, Aizen E M (2007) Glacier changes in the Tien  
1870 Shan as determined from topographic and remotely sensed data. *Glob and Planet Change*,  
1871 56:328-340.

1872 Alcamo J, Kreileman GJJ, Krol MS, Zuidema G (1994) Modeling the global society-  
1873 biosphere-climate system: Part 1: model description and testing. *Water, Air, and Soil  
1874 Pollution* 76(1–2):1–35. doi: 10.1007/BF00478335.

1875 Alcantara C, Kuemmerle T, Baurmann M, Radeloff V (2013) Mapping the extent of  
1876 abandoned farmland in Central and Eastern Europe using MODIS time series satellite data.  
1877 *Environ Res Lett* 8(3):035035. doi: 10.1088/1748-9326/8/3/035035.

1878 Alcantara C, Kuemmerle T, Prishchepov AV, Radeloff VC (2012) Mapping abandoned  
1879 agriculture with multi-temporal MODIS satellite data. *Remote Sensing of Environment*  
1880 124:334–347. doi: 10.1016/j.rse.2012.05.019.

1881 Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell NG, Vennetier M,  
1882 Kitzberger T, Rigling A, Breshears D, Hogg T, Gonzalez P, Fensham R, Zhang Z, Castro  
1883 J, Demidova N, Lim JH, Allard G, Running S, Semerci A, Cobb NS (2010) A global  
1884 overview of drought and heat-induced tree mortality reveals emerging climate risk for  
1885 forests. *Forest Ecology and Management*, 259:660–684. doi: 10.1016/j.foreco.2009.09.001

1886 AMAP (Arctic Monitoring and Assessment Programme) (2011) Snow, Water, Ice and  
1887 Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Report to the  
1888 Arctic Council [Available at <http://amap.no/swipa/>] AMAP, Oslo, Norway.

1889 AMAP (Arctic Monitoring and Assessment Programme) (2017) Snow, Water, Ice, Permafrost  
1890 in the Arctic (SWIPA). Update. <http://www.amap.no/swipa2017>.

1891 Andrew R (2014) *Socio-Economic Drivers of Change in the Arctic*. AMAP Technical Report  
1892 No. 9 Arctic Monitoring and Assessment Programme (AMAP) Oslo Norway

1893 Anisimov O, Kokorev V, Zhil'tsova Y (2013) Temporal and spatial patterns of modern  
1894 climatic warming: case study of Northern Eurasia. *Climate Change* 118(3): 871–883. doi:  
1895 10.1007/s10584-013-0697-4.

1896 Arctic Climate Impact Assessment (ACIA) (2005) Scientific Report, Chapter 2 “Arctic  
1897 Climate: Past and Present” Cambridge University Press

1898 Arora VK, Boer GJ, Friedlingstein P, Eby M, Jones CD, Christian JR, Bonan Bopp GL,  
1899 Brovkin V, Cadule P, Hajima T, Ilyina T, Lindsay K, Tjiputra JF, Wu T (2013) Carbon-  
1900 concentration and carbon-climate feedbacks in CMIP5 earth system models. *J. Climate*  
1901 26:5289–5314. doi: 10.1175/JCLI-D-12-00494.1.

1902 Arzhanov MM, Eliseev AV, Mokhov II (2012a) A global climate model based, Bayesian  
1903 climate projection for northern extra-tropical land areas. *Glob Planet Change* 86–87:57–65.  
1904 doi: 10.1016/j.gloplacha.2012.02.001.

1905 Arzhanov MM, Eliseev AV, Klimenko VV, Mokhov II, Tereshin AG (2012b) Estimating  
1906 climate changes in the Northern Hemisphere in the 21st century under alternative scenarios  
1907 of anthropogenic forcing. *Izvestiya Atmos Ocean Phys* 48(6):573–584. doi:  
1908 10.1134/S0001433812060023

1909 Baklanov AA, Penenko V, Mahura A, Vinogradova A, Elansky N, Tsvetova E, Rigina O,  
1910 Maksimenkov L, Nuterman R, Pogarskii F, and Zakey A (2013) Aspects of atmospheric  
1911 pollution in Siberia. In: Groisman PY and Gutman G (eds) *Environmental Changes in*  
1912 *Siberia: Regional Changes and their Global Consequences*. Springer New York.

1913 Balshi, M. S., A. D. McGuire, Q. Zhuang, J. Melillo, D. W. Kicklighter, E. Kasischke, C.  
1914 Wirth, M. Flannigan, J. Harden, J. S. Clein, T. J. Burnside, J. McAllister, W. A. Kurz, M.  
1915 Apps and A. Shvidenko (2007) The role of historical fire disturbance in the carbon

1916 dynamics of the pan-boreal region: a process-based analysis. *J Geophys Res*  
1917 *Biogeosciences* 112(G2):G02029, doi: 10.1029/2006JG000380...

1918 Barriopedro D, Fischer EM, Luterbacher J, Trigo RM, Garcia-Herrera R (2011) The hot  
1919 summer of 2010: redrawing the temperature record map of Europe. *Science*  
1920 332(6026):220–224. doi: 10.1126/science.1201224.

1921 Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi  
1922 KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea  
1923 PR, White LL (eds) (2014) *Climate Change 2014: Impacts, Adaptation, and Vulnerability*.  
1924 Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment  
1925 Report of the Inter-governmental Panel on Climate Change. Cambridge University Press,  
1926 Cambridge, United Kingdom and New York, USA.

1927 Bartalev SA, Stysenko FV, Egorov BA, Lupyán EA (2015) Satellite estimate of death of  
1928 Russian forests caused by fire. *Forest Science (Lesovedenie)* 2:83–94 (in Russian).

1929 Bastos A, Gouvenia CV, Trigo RM (2014) Analysing the spatio-temporal impacts of the 2003  
1930 and 2010 extreme heatwaves on plant productivity in Europe. *Biogeosciences*  
1931 11(13):3421–3435. doi: 10.5194/bg-11-3421-2014.

1932 Batmunkh T, Kim YJ, Jung JS, Park K, Tumendemberel B (2013) Chemical characteristics of  
1933 fine particulate matters measured during severe winter haze events in Ulaanbaatar,  
1934 Mongolia. *J Air and Waste Management Assoc* 63(6):659–670. doi:  
1935 10.1080/10962247.2013.776997.

1936 Bennett KE, Cannon AJ, Hinzman L (2015) Historical trends and extremes in boreal Alaska  
1937 river basins., *J Hydrol* 527:590–607. doi:10.1016/j.jhydrol.2015.04.065.

1938 Bergen KM, Hitztaler S, Kharuk V, Krainina ON, Loboda T, Zhao TT, Shugart HH, Sun G  
1939 (2013) Human Dimensions of Environmental Change in Siberia. In: Groisman P, Gutman

1940 G (eds) *Regional Environmental Changes in Siberia and Their Global Consequences*.  
1941 Kluwer Academic Publishers, Dordrecht, pp 251–302.

1942 Bergen KM, Zhao T, Kharuk V, Blam Y, Brown DG, Peterson LK, Miller N (2008) Changing  
1943 regimes: forested land cover dynamics in central Siberia 1974 to 2001. *Photogrammetric  
1944 Engineering and Remote Sensing* 74(6):787–798. doi: 10.14358/PERS.74.6.787.

1945 Bičík I, Kupková L, Jeleček L, Kabrda J, Štych P, Janoušek Z, Winklerová J (2015) *Land Use  
1946 Changes in the Czech Republic 1845 – 2010. Socio-Economic Driving Forces* Springer  
1947 New York ISBN: 978–3–319–17670–3

1948 Blunden J, Arndt DS (eds.) (2015) *State of the Climate in 2014*. Bull Amer Meteor Soc,  
1949 96(7):S1–S267. doi: 10.1175/2015BAMSStateoftheClimate.1.

1950 Blunden J, Arndt DS (eds), 2016: *State of the Climate in 2015*. *Bull. Amer. Meteor.  
1951 Soc.*, **97** (8), S1-S275.

1952 Blyakharchuk TA, Tchekakova NM, Parfenova EI, Soja AJ (2014) Potential influence of the  
1953 late Holocene climate on settled farming versus nomadic cattle herding in the Minusinsk  
1954 Hollow, south-central Siberia. *Environ Res Lett* 9(6):065004. doi: 10.1088/1748–  
1955 9326/9/6/065004.

1956 Bohn TJ, Melton JR, Ito A, Kleinen T, Spahni R, Stocker BD, Zhang B, Zhu X, Schroeder R,  
1957 Glagolev MV, Maksyutov S, Brovkin V, Chen G, Denisov SN, Eliseev AV, Gallego-Sala  
1958 A, McDonald KC, Rawlins MA, Riley WJ, Subin ZM, Tian H, Zhuang Q, Kaplan JO  
1959 (2015) WETCHIMP-WSL: Intercomparison of wetland methane emissions models over  
1960 West Siberia. *Biogeosciences* 12:3321–3349. doi: 10.5194/bg-12-3321–2015.

1961 Bohn TJ, Podest E, Schroeder R, Pinto N, McDonald KC, Glagolev M, Filippov I, Maksyutov  
1962 S, Heimann M, Chen X, Lettenmaier DP (2013) Modeling the large-scale effects of surface  
1963 moisture heterogeneity on wetland carbon fluxes in the West Siberian Lowland.  
1964 *Biogeosciences* 10:6559–6576. doi: 10.5194/bg-10–6559–2013.

1965 Bolch T, Marchenko SS (2009) Significance of glaciers, rockglaciers and ice-rich permafrost  
1966 in the Northern Tien Shan as water towers under climate change conditions. In: Braun L,  
1967 Hagg W, Severskiy IV, Young GJ (eds) Selected papers from the Workshop "Assessment  
1968 of Snow, Glacier and Water Resources in Asia" Almaty, Kazakhstan, 28–30 Nov 2006,  
1969 IHP/HWRP-Berichte, 8:132–144.

1970 Bowling LC, Lettenmaier DP (2010) Modeling the effects of lakes and wetlands on the water  
1971 balance of Arctic environments. *J Hydrometeorol* **11**:276–295. doi:  
1972 10.1175/2009JHM1084.1.

1973 Bragina EV, Ives AR, Pidgeon AM, Kuemmerle T, Baskin LM, Gubar YP, Piquer-Rodríguez  
1974 M, Keuler NS, Petrosyan VG, Radeloff VC (2015) Rapid declines of large mammal  
1975 populations after the collapse of the Soviet Union: Wildlife decline after collapse of  
1976 socialism. *Conservation Biology* January 2015. <https://doi.org/10.1111/cobi.12450>.

1977 Brovkin V, Boysen L, Arora VK, Boisier JP, Cadule P, Chini L, Claussen M, Friedlingstein  
1978 P, Gayler V, Van Den Hurk BJM, Hurt GC (2013) Effect of anthropogenic land-use and  
1979 land-cover changes on climate and land carbon storage in CMIP5 projections for the  
1980 twenty-first century *J Climate* 26(18):6859–6881. doi: 10.1175/JCLI-D-12-00623.1.

1981 Brovkin V, Claussen M, Driesschaert E, Fichefet T, Kicklighter D, Loutre MF, Matthews HD,  
1982 Ramankutty N, Schaeffer M, Sokolov A (2006) Biogeophysical effects of historical land  
1983 cover changes simulated by six earth system models of intermediate complexity. *Climate  
1984 Dynamics* 26(6):587–600. doi: 10.1007/s00382-005-0092-6.

1985 Brown RD, Robinson DA (2011) Northern Hemisphere spring snow cover variability and  
1986 change over 1922–2010 including an assessment of uncertainty. *The Cryosphere* 5:219–  
1987 229. doi: 10.5194/tc-5-219-2011.

1988 Bulygina ON, Arzhanova NM, Groisman PY (2015) Icing conditions over Northern Eurasia  
1989 in changing climate. *Environ Res Lett* 10(2):025003. doi: 10.1088/1748–  
1990 9326/10/2/025003.

1991 Bulygina ON, Groisman PY, Razuvaev VN, Korshunova NN (2011) Changes in snow cover  
1992 characteristics over Northern Eurasia since 1966. *Environ Res Lett* 6(4):045204. doi:  
1993 10.1088/1748–9326/6/4/045204.

1994 Bulygina ON, Korshunova NN, Razuvaev VN (2013) Change of the near-surface winds over  
1995 Russia during the past decades. *Transact Voeikov Main Geophys Observ* 568:156–72 (in  
1996 Russian)

1997 Bulygina ON, Razuvaev VN, Korshunova NN (2009) Changes in snow cover over Northern  
1998 Eurasia in the last few decades. *Environ Res Lett* 4(4):045026. doi: 10.1088/1748–  
1999 9326/4/4/045026.

2000 Callaghan TV, Johansson M, Brown RD, Groisman PY, Labba N, Radionov V, Barry RS,  
2001 Bulygina ON, Essery RLH, Frolov DM, Golubev VN, Granfell TC, Petrushina MN,  
2002 Razuvaev VN, Robinson DA, Romanov P, Shindell D, Shmakin AB, Sokratov SA, Warren  
2003 S, Yang D (2011a) The changing face of Arctic snow cover: a synthesis of observed and  
2004 projected changes. *Ambio* 40(Suppl 1):17–31. doi: 10.1007/s13280–011–0212–y.

2005 Callaghan TV, Johansson M, Brown RD, Groisman PY, Labba N, Radionov V, Bradley RS,  
2006 Blangy S, Bulygina ON, Christensen TR, Colman JE, Essery RLH, Forbes BC,  
2007 Forchhammer MC, Golubev VN, Honrath NE, Juday JP, Meshcherskaya AV, Phoenix GK,  
2008 Pomeroy J, Rautio A, Robinson DA, Schmidt NH, Serreze MC, Shevchenko VP,  
2009 Shiklomanov AI, Shmain AB, Skold P., Sturm M, Woo M, Wood EF (2011b) Multiple  
2010 effects of changes in Arctic snow cover. *Ambio* 40 (Suppl. 1):32–45. doi: 10.1007/s13280–  
2011 011–0213–x.

2012 Campbell PKE, Rock BN, Martin ME, Neefus CD, Irons JR, Middleton EM, Albrechtová J  
2013 (2004) Detection of initial damage in Norway spruce canopies using hyperspectral airborne  
2014 data. *Int J Remote Sens* 25(24):5557–5584. doi: 10.1080/01431160410001726058.

2015 Chen F-H, Yu Z, Yang M, Ito E, Wang S, Madsen DB, Huang X, Zhao Y, Sato T, Birks HJB,  
2016 Boomer I, Chen J, An C, Wünnemann B (2008) Holocene moisture evolution in arid  
2017 central Asia and its out-of-phase relationship with Asian monsoon history, *Quaternary  
2018 Science Reviews* 27(3–4):351–364. doi: 10.1016/j.quascirev.2007.10.017.

2019 Chen F-H, Chen J-H, Holmes J, Boomer I, Austin P, Gates JB, Wang N-L, Brooks SJ, Zhang  
2020 J-W (2010) Moisture changes over the last millennium in arid central Asia: a review,  
2021 synthesis and comparison with monsoon region. *Quaternary Science Reviews* 29(7–  
2022 8):1055–1068. doi: 10.1016/j.quascirev.2010.01.005.

2023 Chen J, Liu Y (eds) (2014) Coupled natural and human systems: A landscape ecology  
2024 perspective. *Landscape Ecology* 29.

2025 Chen J, John R, Shao C, Fan Y, Zhang Y, Amarjargal A, Brown DG, Qi J, Han J, Laforteza  
2026 R, Dong G (2015a) Policy shifts influence the functional changes of the CNH systems on  
2027 the Mongolian plateau. *Environ Res Lett* 10(8):085003, doi: 10.1088/1748–  
2028 9326/10/8/085003.

2029 Chen J, John R, Zhang Y, Shao C, Brown DG, Batkhishig O, Amarjargal A, Ouyang Z, Dong  
2030 G, Qi J (2015b) Divergences of two coupled human and natural systems on the Mongolia  
2031 Plateau. *BioScience* 65(6):559–570. doi: 10.1093/biosci/biv050.

2032 Chen J, Wan S, Henebry G, Qi J, Gutman G, Sun G, Kappas M (eds) (2013) *Dryland East  
2033 Asia: Land Dynamics Amid Social and Climate Change*. Beijing: Higher Education Press  
2034 Berlin: De Gruyter.

2035 Chen Y, Zhai P (2014) Two types of typical circulation pattern for persistent extreme  
2036 precipitation in Central-Eastern China. *Quart J Roy Meteorol Soc* 140(682):1467–1478.

2037 Chen YZ, Ju W, Groisman PY, Li J, Propastin P, Xu X, Zhou W, Ruan H (2017) Quantitative  
2038 assessment of carbon sequestration reduction induced by disturbances in Temperate  
2039 Eurasian Steppe. *Environ Res Lett* 12, doi: iopscience.iop.org/article/10.1088/1748-  
2040 9326/aa849b.

2041 Conard SG, Sukhinin AI, Stocks BJ, Cahoon DR, Davidenko EP, Ivanova GA (2002)  
2042 Determining effects of area burned and fire severity on carbon cycling and emissions in  
2043 Siberia. *Clim. Change* 55(1–2):197–211. doi: 10.1023/A:1020207710195.

2044 Cook BI, Anchukaitis KJ, Touchan R, Meko DM, Cook ER (2016) Spatiotemporal drought  
2045 variability in the Mediterranean over the last 900 years. *J Geophys Res Atmos* 121:2060–  
2046 2074. doi: 10.1002/2015JD023929.

2047 Core Writing Team, Pachauri RK, Reisinger A. (eds) (2007) Climate Change 2007: Synthesis  
2048 Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of  
2049 the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

2050 Crate SA (2006) Cows, kin, and globalization: an aethnography of sustainability. Rowman  
2051 Altamira.

2052 Cresto-Aleina F, Brovkin V, Muster S, Boike J, Kutzbach L, Sachs T, Zuyev S (2013) A  
2053 stochastic model for the polygonal tundra based on Poisson-Voronoi diagrams. *Earth*  
2054 *System Dynamics* 4:187–198. doi: 10.5194/esd-4–187–2013.

2055 Cresto-Aleina F, Runkle BRK, Kleinen T, Kutzbach L, Schneider J, Brovkin V (2015)  
2056 Modeling micro-topographic controls on boreal peatland hydrology and methane fluxes.  
2057 *Biogeosciences*, 12:5689–5704. doi: 10.5194/bg-12–5689–2015.

2058 Crowley RM (2005) Stepping on to a moving train: the collision of illegal logging, forestry  
2059 policy, and emerging free trade in the Russian Far East. *Pacific Rim Law and Pol J*  
2060 Dargaville RJ, Heimann M, McGuire AD, Prentice IC, Kicklighter DW, Joos F, Clein JS,  
2061 Esser G, Foley J, Kaplan J, Meier RA, Melillo JM, B. Moore III B, Ramankutty N,

2062 Reichenau T, Schloss A, Sitch S, Tian H, Williams LJ Wittenberg U (2002b) Evaluation of  
2063 terrestrial carbon cycle models with atmospheric CO<sub>2</sub> measurements: Results from  
2064 transient simulations considering increasing CO<sub>2</sub>, climate and land-use effects. *Global*  
2065 *Biogeochemical Cycles* 16(4):1092, doi: 10.1029/2001GB001426.

2066 Dargaville RJ, McGuire AD, Rayner P (2002a) Estimates of large-scale fluxes in high  
2067 latitudes from terrestrial biosphere models and an inversion of atmospheric CO<sub>2</sub>  
2068 measurements. *Climatic Change* 55(1–2):273–285. doi: 10.1023/A:1020295321582.

2069 Darmenova K, Sokolik IN, Shao Y, Marticorena B, Bergametti G (2009): Development of a  
2070 physically-based dust emission module within the Weather Research and Forecasting  
2071 (WRF) model: Assessment of dust emission parameterizations and input parameters for  
2072 source regions in Central and East Asia. *J Geophys Res* 114: D14201. doi:  
2073 10.1029/2008JD011236.

2074 Dass P, Rawlins MA, Kimball JS, Kim Y (2016) Environmental controls on the increasing  
2075 GPP of terrestrial vegetation across northern Eurasia. *Biogeosciences* 13:45–62. doi:  
2076 10.5194/bg-13–45.2016.

2077 Davydov SP, Fedorov-Davydov DG, Neff JC, Shiklomanov NI, Davydova AI (2008)  
2078 Changes in Active Layer Thickness and Seasonal Fluxes of Dissolved Organic Carbon as a  
2079 Possible Baseline for Permafrost Monitoring. In: Proceedings of the 9th International  
2080 Conference on Permafrost, Institute of Northern Engineering, University of Alaska,  
2081 Fairbanks, June 29 – July 3, 2008.

2082 de Beurs KM, Ioffe G (2014) Use of Landsat and MODIS data to remotely estimate Russia's  
2083 sown area. *J. Land Use Sci.* 9(4):377–401. <http://doi.org/10.1080/1747423X.2013.798038>

2084 de Beurs KM, Henebry GM, Owsley BC, Sokolik I (2015) Using multiple remote sensing  
2085 perspectives to identify and attribute land surface dynamics in Central Asia 2001–2013.  
2086 *Remote Sensing of Environment* 170:48–61. <http://dx.doi.org/10.1016/j.rse.2015.08.018>

2087 DeLucia EH (2015) How biofuels can cool our climate and strengthen our ecosystems. *Eos*  
2088 96(4):14–19. doi: 10.1029/2015EO041583.

2089 Derevyagin VA (1987) Practical Guidance on Straw Utilization as Fertilizer. All-Union  
2090 Research and Development, USSR State Agro-Industrial Committee on Design and  
2091 Technological Institute for Organic Fertilizers and Peat, Moscow, Russia.  
2092 <http://quickr.mtri.org/croplandburning>.

2093 Derome J, Lukina N (2011) Interaction between environmental pollution and land-cover/land-  
2094 use change in arctic areas. In: Gutman G, Reissell A (eds) *Eurasian Arctic Land Cover and*  
2095 *Land Use in a Changing Climate*. Springer, Dordrecht:

2096 Dienes L (2004) Observations on the problematic potential of Russian oil and the  
2097 complexities of Siberia. *Eurasian Geogr Econ* 45(5):319–345. doi: 10.2747/1538–  
2098 7216.45.5.319.

2099 Dolman AJ, Shvidenko A, Schepaschenko D, Ciais P, Tchebakova NM, Chen T, van der  
2100 Molen MK, Belletti Marchesini L, Maximov TC, Maksyutov S, Schulze E-D (2012) An  
2101 estimate of the terrestrial carbon budget of Russia using inventory-based, eddy covariance  
2102 and inversion methods. *Biogeosciences* 9:5323–5340. doi: 10.5194/bg-9–5323–2012.

2103 Dronin N, Kirilenko A (2010) Climate change, food stress, and security in Russia. *Regional*  
2104 *Environmental Change* 11(Supplement 1):167–178. <http://doi.org/10.1007/s10113–010–0165-x>.

2106 Drozdov OA (1966) On the variation of precipitation over the northern hemisphere with  
2107 variation of the temperature of the polar basin. *Transactions of the Main Geophys Observ*  
2108 138:3–16 (in Russian).

2109 Dubinin M, Lushchekina A, Radeloff VC (2011) Climate, livestock and vegetation: what  
2110 drives fire increase in the arid ecosystems of Southern Russia? *Ecosystems* 14(4):547–562.  
2111 doi: 10.1007/s10021–011–9427.9.

2112 Duethmann D, Bolch T, Farinotti D, Kriegel D, Vorogushyn S, Merz B, Pieczonka T, Jiang T,  
2113 Su B, Guntner A (2015) Attribution of streamflow trends in snow and glacier melt-  
2114 dominated catchments of the Tarim River, Central Asia. *Water Resourc Res* **51**(6):4727–  
2115 4750. doi: 10.1002/2014WR016716.

2116 Eby M, Weaver AJ, K. Alexander K, Zickfeld K, A. Abe-Ouchi A, Cimatoribus AA, Crespin  
2117 E, DrijfhoutSS, Edwards NR, Eliseev AV, Feulner G, T. Fichefet T, Forest CE., Goosse H,  
2118 Holden PB, Joos F, Kawamiya M, Kicklighter D, Kienert H, Matsumoto K, Mokhov II.  
2119 Monier E, Olsen SM, Pedersen JOP, Perrette M, Philippon-Berthier G, Ridgwell A,  
2120 SchlosserA, Schneider von Deimling T, Shaffer G, Smith RS, Spahni R, Sokolov AP.,  
2121 Steinacher M, Tachiiri K, K. Tokos K, Yoshimori M, Zeng N, Zhao F (2013) Historical  
2122 and idealized climate model experiments: an intercomparison of Earth system models of  
2123 intermediate complexity. *Climate of the Past* **9**:1111–1140. doi: 10.5194/cp-9–1111–2013.

2124 Estel S, Kuemmerle T, Alcántara C, Levers C, Prishchepov A, Hostert P (2015) Mapping  
2125 farmland abandonment and recultivation across Europe using MODIS NDVI time series.  
2126 *Remote Sensing of Environment* **163**:312–325. <http://doi.org/10.1016/j.rse.2015.03.028>.

2127 European Forest Institute (2014). Trade Reports Database. Joensuu, Finland  
2128 (URL: [http://www.efi.int/portal/virtual\\_library/databases/forest\\_products\\_trade\\_flow\\_data](http://www.efi.int/portal/virtual_library/databases/forest_products_trade_flow_data)  
2129 base/ last accessed 8–21–2017)

2130 Euskirchen ES, McGuire AD, Kicklighter DW, Zhuang Q, Clein JS, Dargaville RJ, Dye DG,  
2131 Kimball JS, McDonald KC, Melillo JM, Romanovsky VE, Smith NV (2006) Importance  
2132 of recent shifts in soil thermal dynamics on growing season length, productivity and  
2133 carbon sequestration in terrestrial high-latitude ecosystems. *Global Change Biology*  
2134 **12**(4):731–750. doi: 10.1111/j.1365-2486.2006.01113.x.

2135 Farinotti D, Longuevergne L, Moholdt G, Duethmann D, Mölg T, Bolch T, Vorogushyn S,  
2136 Güntner A (2015) Substantial glacier mass loss in the Tien Shan over the past 50 years.  
2137 *Nature Geoscience* 8:716–722. doi: 10.1038/ngeo2513.

2138 Farré AB, Stephenson S, Chen L, Wighting J (2014) Commercial Arctic shipping through the  
2139 Northeast Passage: routes, resources, governance, technology, and infrastructure. *Polar  
2140 Geography* 37(4):298–324. doi: 10.1080/1088937X.2014.965769.

2141 Fausto RS, van As D, Box JE, Colgan W, Langen PL, Mottram RH (2016) The implication of  
2142 non-radiative energy fluxes dominating Greenland ice sheet exceptional ablation area  
2143 surface melt in 2012. *Geophys Res Lett* 43:2649–2658. doi: 10.1002/2016GL067720.

2144 Fichot CG, Kaiser K, Hooker SB, Amon RMW, Babin M, Bélanger S, Walker SA, Benner R,  
2145 (2013) Pan-Arctic distributions of continental runoff in the Arctic Ocean. *Scientific  
2146 Reports* 3:1053. doi: 10.1038/srep01053.

2147 Fjellstad WJ, Dramstad WE (1999) Patterns of change in two contrasting Norwegian  
2148 agricultural landscapes. *Landscape and Urban Planning* 45(4):177-191. doi:  
2149 10.1016/S0169-2046(99)00055-9.

2150 Flannigan MD, Cantin AS, de Groot WJ, Wotton M, Newbery A, Gowman LM (2013) Global  
2151 wildland fire season severity in the 21<sup>st</sup> century. *Forest Ecology and Management* 294:54–  
2152 61. doi: 10.1016/j.foreco.2012.10.022.

2153 Flannigan MD, Stocks BJ, Wotton BM (2000) Climate change and forest fires. *The Science  
2154 of the Total Environment* 262(3):221–229. doi: 10.1016/S0048-9697(00)00524-6.

2155 Fondahl GA (1996) Contested Terrain: Changing Boundaries and Identities in Southeastern  
2156 Siberia. *Post-Soviet Geography and Economics* 37(1):3-15. doi:  
2157 10.1080/10889388.1996.10641011.

2158 Forbes BC, Kumpula T, Meschtyb N, Laptander R, Macias-Fauria M, Zetterberg P, Verdonen  
2159 M, Skarin A, Kim KY, Boisvert LN, Stroeve JC, Bartsch A (2016) Sea ice, rain-on-snow

2160 and tundra reindeer nomadism in Arctic Russia. Biol Lett 12:2160466.  
2161 <http://dx.doi.org/10.1098/rsbl.2016.0466>.

2162 Forbes BC, Stammler F, Kumpula T, Meschtyb N, Pajunen A, Kaarlejärvi E (2009) High  
2163 resilience in the Yamal-Nenets social-ecological system, West Siberian Arctic, Russia.  
2164 Proc Natl Acad Sci USA 106(52):22041–22048. doi: 10.1073/pnas.0908286106.

2165 Fottová D, (1995) Regional evaluation of mass element fluxes: GEOMON network of small  
2166 catchments. Environ Monit Assess 34(2):215–221. doi: 10.1007/BF00546037.

2167 Francis JA, Vavrus SJ (2012) Evidence linking Arctic amplification to extreme weather in  
2168 mid-latitudes. Geophys Res Lett 39:L06801. doi: 10.1029/2012GL051000.

2169 Frauenfeld OW, Zhang T (2011). An observational 71-year history of seasonally frozen  
2170 ground changes in the Eurasian high latitudes. Environ Res Lett 6 044024.  
2171 doi:10.1088/1748-9326/6/4/044024.

2172 Frauenfeld OW, ZhangT, Barry RG, Gilichinsky D. (2004). Interdecadal changes in seasonal  
2173 freeze and thaw depths in Russia. J. Geophys. Res. 109 D5101.

2174 Friedlingstein P, Cox P, Betts R, Bopp L, von Bloh W, Brovkin V, Cadule P, Doney S, Eby  
2175 M, Fung I, Bala G, John J, Jones C, Joos F, Kato T, Kawamiya M, Knorr W, Lindsay  
2176 K, Matthews HD, Raddatz T, Rayner P, Reick C, Roeckner E, Schnitzler KG, Schnur R,  
2177 Strassmann K, Weaver AG, Yoshikawa C, Zeng N (2006) Climate-carbon cycle feedback  
2178 analysis: results from the C4MIP model intercomparison. J Climate 19(14):3337–3353.  
2179 doi: 10.1175/JCLI3800.1.

2180 Gálos B, Hagemann S, Hänsler A, Kindermann G, Rechid D, Sieck K, Teichmann C, Jacob D  
2181 (2013) Case study for the assessment of the biogeophysical effects of a potential  
2182 afforestation in Europe. Carbon Balance and Management, 8(3), doi: 10.1186/1750-0680–  
2183 8–3.

2184 Gannon M (2016) Arctic sea ice extent may shrink below 2012 record low. *EOS* 97. doi:  
2185 10.1029/2016EO051183.

2186 Gao X, Schlosser CA, Sokolov A, Walter Anthony K, Zhuang Q, Kicklighter D (2013)  
2187 Permafrost degradation and methane: low risk of biogeochemical climate-warming  
2188 feedback. *Environ Res Lett* 8(3):035014. doi: 10.1088/1748–9326/8/3/035014.

2189 Gauthier S, Bernier P, Kuuluvainen T, Shvidenko AZ, Schepaschenko DG (2015) Boreal  
2190 forest health and global change. *Science* 349(6250):819–822. doi:  
2191 10.1126/science.aaa9092.

2192 Gelfan A (2011) Modelling hydrological consequences of climate change in the permafrost  
2193 region and assessment of their uncertainty. In: Yang D, Marsh D, Gelfan A (eds) *Cold*  
2194 *Region Hydrology in a Changing Climate*. IAHS Publications 346:92–97.

2195 Gelfan A, Muzylev E, Uspensky A, Startseva Z, Romanov P (2012) Remote sensing based  
2196 modeling of water and heat regimes in a vast agricultural region. Chapter 6 In: B.  
2197 Escalante-Ramirez (ed) *Remote Sensing - Applications* ISBN: 978–953–51–0651–7,  
2198 InTechOpen d.o.o. Rijeka Croatia. doi: 10.5772/37076.

2199 Georgiadi AG, Kashutina EA (2016) Long-term runoff changes of the largest Siberian Rivers.  
2200 *Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya*. 2016(5):70–81. doi:  
2201 10.15356/0373–2444–2016–5–70–81 (in Russian).

2202 Georgiadi AG, Koronkevich N, Milyukova IP, Barabanova EA (2014a) The ensemble  
2203 scenarios projecting runoff changes in large Russian river basins in the 21st century,  
2204 *Evolving Water Resources Systems: Understanding, Predicting and Managing Water–*  
2205 *Society Interactions*. Proceedings of ICWRS2014, Bologna, Italy, June 2014 (IAHS Publ.  
2206 364). doi: 10.5194/piahs-364–210-2014.

2207 Georgiadi AG, Koronkevich NI, Milyukova IP, Kashutina EA, Barabanova EA (2014b)

2208 Contemporary and scenario River runoff changes in the largest rivers of Russia. Part 2.

2209 The Volga and Don River Basins. Maks Press, Moscow (in Russian).

2210 Georgiadi AG, Koronkevich NI, Miliukova IP, Kislov AV, Anisimov OA, Barabanova EA,

2211 Kashutina EA, Borodin OO (2011) Scenario assessment of probable river runoff changes

2212 of the largest rivers of Russia. Part 1. Lena River Basin. Max Press, Moscow (in Russian).

2213 Georgiadi AG, Milyukova IP, Kashutina EA (2010) Response of River Runoff in the

2214 Cryolithic Zone of Eastern Siberia (Lena River Basin) to Future Climate Warming. In

2215 Environmental Change in Siberia (pp. 157–169). Springer Netherlands. doi:10.1007/978–

2216 90–481–8641–9\_10.

2217 Glagolev M, Kleptsova I, Filippov I, Maksyutov S, Machida T (2011) Regional methane

2218 emission from West Siberia mire landscapes. Environ Res Lett 6(4):045214.

2219 doi:10.1088/1748–9326/6/4/045214.

2220 Goldammer JG (ed) (2013) Vegetation Fires and Global Change: Challenges for Concerted

2221 International Action. A White Paper directed to the United Nations and International

2222 Organizations. A publication of the Global Fire Monitoring Center (GFMC). Kessel Publ

2223 House. ISBN 978–3–941300–78–1 (<http://www.forestrybooks.com/>).

2224 Golubev VS, Lawrimore JH, Groisman PY, Speranskaya NA, Zhuravin SA, Menne MJ,

2225 Peterson TC, Malone RW, (2001) Evaporation changes over the contiguous United States

2226 and the former USSR: A reassessment. Geophys Res Lett 28:2665–2668. doi:

2227 10.1029/2000GL012851.

2228 Goudie AS, Middleton NJ (1992) The changing frequency of dust storms through time.

2229 Climatic Change 20(3):197–225. doi: 10.1007/BF00139839.

2230 Gouttevin I, Krinner G, Ciais P, Polcher J, Legout C (2012) Multi-scale validation of a new  
2231 soil freezing scheme for a land-surface model with physically-based hydrology. *The  
2232 Cryosphere* 6:407–430. doi: 10.5194/tc-6-407-2012.

2233 Graven HD, Keeling RF, Piper SC, Patra PK, Stephens BB, Wofsy SC, Welp LR, Sweeney C,  
2234 Tans PP, Kelley JJ, Daube BC, Kort EA, Santoni GW, Bent JD (2013) Enhanced Seasonal  
2235 Exchange of CO<sub>2</sub> by Northern Ecosystems Since 1960. *Science* 341:1085–1089.  
2236 doi:10.1126/science.1239207.

2237 Griffiths P, Müller D, Kuemmerle T, Hostert P (2013) Agricultural land change in the  
2238 Carpathian ecoregion after the breakdown of socialism and expansion of the European  
2239 Union. *Environ Res Lett* 8(4):045024. doi: 10.1088/1748–9326/8/4/045024.

2240 Groisman PY, Bartalev SA (2007) Northern Eurasia Earth Science Partnership Initiative  
2241 (NEESPI): Science plan overview. *Global and Planetary Change* 56(3–4):215–234. doi:  
2242 10.1016/j.gloplacha.2006.07.027.

2243 Groisman PY, Gutman G (eds) (2013) Environmental Changes in Siberia: Regional Changes  
2244 and their Global Consequences. Springer, Dordrecht.

2245 Groisman PY, Lyalko VI (eds) (2012) Earth Systems Change over Eastern Europe.  
2246 Akademperiodyka, Kiev, Ukraine. ISBN 978-966-360-195-3.

2247 Groisman PY, Soja AJ (2009) Ongoing climatic change in Northern Eurasia: justification for  
2248 expedient research. *Environ. Res. Lett.*, 4(4):045002. doi: 10.1088/1748–9326/4/4/045002.

2249 Groisman PY, Blyakharchuk TA, Chernokulsky AV, Arzhanov MM, Belelli Marchesini L,  
2250 Bogdanova EG, Borzenkova II, Bulygina ON, Karpenko AA, Karpenko LV, Knight RW,  
2251 Khon VCh, Korovin GN, Meshcherskaya AV, Mokhov II, Parfenova EI, Razuvaev VN,  
2252 Speranskaya NA, Tchebakova NM, Vygodskaya NN (2013a) Climate changes in Siberia.  
2253 Ch. 3 In: Groisman PY, Gutman G (eds) (2013) Environmental Changes in Siberia:

2254      Regional Changes and their Global Consequences. Springer, Dordrecht. doi: 10.1007/978–  
2255      94–007–4569–8.

2256      Groisman PY, Bogdanova EG, Alexeev VA, Cherry JE, Bulygina ON (2014) Impact of  
2257      snowfall measurement deficiencies on quantification of precipitation and its trends over  
2258      Northern Eurasia. *Ice and Snow* 2 (126):29–43.

2259      Groisman PY, Bulygina ON, Yin X, Vose RS, Gulev SK, Hanssen-Bauer I, Førland E (2016)  
2260      Recent changes in the frequency of freezing precipitation in North America and Northern  
2261      Eurasia. *Environ Res Lett* 11:045007. doi: 10.1088/1748–9326/11/4/045007.

2262      Groisman, PY, Clark EA, Lettenmaier DP, Kattsov VM, Sokolik IN, Aizen VB, Cartus O,  
2263      Chen J, Schmullius CC, Conard S, Katzenberber J, Krankina O, Kukkonen J, Sofiev M,  
2264      Machida T, Maksyutov S, Ojima D, Qi J, Romanovsky VE, Walker D, Santoro M,  
2265      Shiklomanov AI, Vöröshmarty C, Shimoyama K, ShugaART hh, Shuman JK, Sukhinin  
2266      AI, Wood EF (2009) The Northern Eurasia Earth Science Partnership: An Example of  
2267      Science Applied To Societal Needs. *Bull Amer Meteorol Soc* 90(5):671–688.  
2268      doi:10.1175/2008BAMS2556.1.

2269      Groisman PY, Knight RW, Zolina OG (2013b) Recent trends in regional and global extreme  
2270      precipitation patterns. Chapter 5.03. In: Pielke R Sr, Hossain F (eds) *Climate*  
2271      *Vulnerability: Understanding and Addressing Threats to Essential Resources*. Volume 5,  
2272      *Vulnerability of Water Resources to Climate*. Elsevier Publishing House, Amsterdam.  
2273      ISBN 978–0–12– 384703–4.

2274      Groisman PY, Sun B, Vose RS, Lawrimore JH, Whitfield PH, Førland E, Hanssen-Bauer I,  
2275      Serreze MC, Razuvaev VN, Alekseev GV (2003) Contemporary climate changes in high  
2276      latitudes of the Northern Hemisphere: Daily time resolution. WMO/TD - 1172, [Proc. of  
2277      the International Symposium on Climate Change, Beijing, China, 31 March – 3 April,  
2278      2003], *World Meteorol. Organ. Publ.* # 1172:51–55.

2279 Guha-Sapir D (2010) Disasters in numbers 2010 – presentations. EM-DAT: the international  
2280 disaster database centre for research on the epidemiology of disasters – CRED. Available  
2281 via [http://cred.be/sites/default/files/Disaster\\_numbers\\_presentation\\_2010.pdf](http://cred.be/sites/default/files/Disaster_numbers_presentation_2010.pdf). Accessed  
2282 23 October 2012.

2283 Gurevich E (2009) Influence of air temperature on the river runoff in winter (the Aldan river  
2284 catchment case study). *Russian Meteorology and Hydrology* 34(9):628–633. doi:  
2285 10.3103/S1068373909090088.

2286 Gustafson EJ, Shvidenko AZ, Scheller RM (2011a) Effectiveness of forest management  
2287 strategies to mitigate effects of global change in south-central Siberia. *Canadian J Forest  
2288 Res* 41(7):1405–1421. doi: 10.1139/x11–065.

2289 Gustafson EJ, Shvidenko AZ, Sturtevant BR, Sheller RM (2011b) Using landscape  
2290 disturbance and succession models to support forest management. In: Li C, Laforteza R,  
2291 Chen J (eds) *Landscape ecology in forest management and conservation*. HEP and  
2292 Springer, Beijing and Berlin.

2293 Gustafsson Ö, van Dongen BE, Vonk JE, Dudarev OV, Semiletov IP 2011: Widespread  
2294 release of old carbon across the Siberian Arctic echoed by its large rivers. *Biogeosciences*,  
2295 8:1737–1743. doi: 10.5194/bg-8–1737–2011.

2296 Gutman G, Radeloff VC (eds) (2016) *Land Use and Land Cover Change in Eastern Europe  
2297 after the Collapse of the Soviet Union in 1991*. Springer, Dordrecht.

2298 Gutman G, Reissell A (eds) (2011) *Arctic land cover and land use in a changing climate:  
2299 Focus on Eurasia*. VI, Springer, Amsterdam.

2300 Hagg W, Braun LN, Weber M, Becht M (2006) Runoff modelling in glacierized Central  
2301 Asian catchments for present-day and future climate. *Hydrol Res* 37(2):93–105. doi:  
2302 10.2166/nh.2006.001

2303 Hagg W, Hoelzle M, Wagner S, Mayr E, Klose Z (2013) Glacier and runoff changes in the  
2304 Rukhk catchment, upper Amu-Darya basin until 2050. *Global and Planetary Change*  
2305 110:62–73. doi: 10.1016/j.gloplacha.2013.05.005.

2306 Hallgren W, Schlosser CA, Monier E, Kicklighter D, Sokolov A, Melillo J (2013) Climate  
2307 impacts of a large-scale biofuels expansion. *Geophys Res Lett* 40(8):1624–1630. doi:  
2308 10.1002/grl.50352.

2309 Hashim SM (2010) Power-loss of power-transition? Assessing the limits of using the energy  
2310 sector in reviving Russia's geopolitical stature. *Communist Post-Communist Stud* 43:263–  
2311 274.

2312 Hayes DJ, Kicklighter DW, McGuire AD, Chen M, Zhuang Q, Yuan F, Melillo JM,  
2313 Wullschleger SD (2014) The impacts of recent permafrost thaw on land-atmosphere  
2314 greenhouse gas exchange. *Environ Res Lett* 9:045005. doi: 10.1088/1748–  
2315 9326/9/4/045005.

2316 Hayes DJ, McGuire AD, Kicklighter DW, Burnside TJ, Melillo JM (2011a) The effects of  
2317 land cover and land use change on the contemporary carbon balance of the arctic and  
2318 boreal terrestrial ecosystems of northern Eurasia. pp. 109–136. In: Gutman G., Reissell A  
2319 (eds) *Eurasian Arctic Land Cover and Land Use in a Changing Climate*. Springer, New  
2320 York. doi: 10.1007/978–90–481–9118–5\_6.

2321 Hayes DJ, McGuire AD, Kicklighter DW, Gurney KR, Burnside TJ, Melillo JM (2011b) Is  
2322 the northern high–latitude land-based CO<sub>2</sub> sink weakening? *Global Biogeochemical Cycles*  
2323 25(3):GB3018. doi: 10.1029/2010GB003813.

2324 Heleniak T (2010) Migration and Population Change in the Russian Far North during the  
2325 1990s. In: Southcott C., Huskey L. (eds) *Migration in the Circumpolar North: Issues and*  
2326 *Contexts*. Canadian Circumpolar Institute Press, University of Alberta: Edmonton, Alberta,  
2327 Canada.

2328 Heleniak T (2014) Migration, Arctic. In: Michalos AC (ed) Encyclopedia of Quality of Life  
2329 Research. Springer, Dordrecht, Netherlands.

2330 Heleniak T (2015) Population Change in the Former Communist States of Europe and Asia.  
2331 Intern Encycl Social Behavioral Sci:545–552 doi:10.1016/B978-0-08-097086-8.31037-6

2332 Henebry GM, de Beurs KM, Wright CK, John R, Lioubimtseva E (2013) Dryland East Asia  
2333 in Hemispheric Context. In: Chen J, Wan S, Henebry GM, Qi J, Gutman G, Sun G, Kappas  
2334 M (eds) Dryland East Asia: Land Dynamics Amid Social and Climate Change. Beijing:  
2335 Higher Education Press Berlin: De Gruyter.

2336 Higgins PAT, Harte J (2006) Biophysical and biogeochemical responses to climate change  
2337 depend on dispersal and migration. BioScience 56(5):407–417. doi: 10.1641/0006–  
2338 3568(2006)056[0407: BABRTC]2.0.CO;2.

2339 Higgins SI, Richardson DM (1999) Predicting plant migration rates in a changing world: The  
2340 role of long-distance dispersal. Amer Naturalist 153(5):464–475. doi: 10.1086/303193.

2341 Hijioka Y, Matsuoka M, Nishimoto H, Masui T, Kainuma M (2008) Global GHG emission  
2342 scenarios under GHG concentration stabilization targets. J Glob Environ Eng 13:97–108.

2343 Hitztaler SK, Bergen KM (2013) Mapping Resource Use over a Russian Landscape: An  
2344 Integrated Look at Harvesting of a Non-Timber Forest Product in Central Kamchatka.  
2345 Environ Res Lett 8(4):045020. doi: 10.1088/1748-9326/8/4/045020.

2346 Holmes RM, Coe MT, Fiske GJ, Gurtovaya T, McClelland JW, Shiklomanov AI, Spencer  
2347 RG, Tank SE, Zhulidov, AV (2013) Climate change impacts on the hydrology and  
2348 biogeochemistry of Arctic rivers. Climatic Change and Global Warming of Inland Waters:  
2349 Impacts and Mitigation for Ecosystems and Societies 3–26.

2350 Holmes RM, Shiklomanov AI, Tank SE, McClelland JW, Tretiakov M (2015) River  
2351 Discharge, Arctic Report Card: Update for 2015.  
2352 [http://www.arctic.noaa.gov/reportcard/river\\_discharge.html](http://www.arctic.noaa.gov/reportcard/river_discharge.html).

2353 Horion S, Prishchepov AV, Verbesselt J, de Beurs K, Tagesson T, Fensholt R (2016)

2354 Revealing turning points in ecosystem functioning over the Northern Eurasian agricultural

2355 frontier. *Global Change Biology* 22:2801–2817. doi: 10.1111/gcb.13267.

2356 Hostert P, Kuemmerle T, Prishchepov A, Sieber A, Lambin EF, Radeloff VC (2011) Rapid

2357 land use change after socio-economic disturbances: The collapse of the Soviet Union

2358 versus Chernobyl. *Environ Res Lett* 6(4):045201. doi:10.1088/1748–9326/6/4/045201.

2359 Huang LK, Wang GZ, Mu DY, Xia Z, Wang W (2016) Seasonal-varied chemical

2360 characteristics and pollution sources of PM2.5 in Harbin, China. *Fresenius Env Bull*

2361 25(4):1183–1198.

2362 Huntley B, Birks HJB (1983) An atlas of past and present pollen maps for Europe. Cambridge

2363 University Press, Cambridge-London-New York-New Rochelle-Melbourne-Sydney.

2364 Hurtt GC, Chini LP, Frolking S, Betts RA, Feddema J, Fischer G, Fisk GP, Hibbard K,

2365 Houghton RA, Janetos A, Jones CD, Kindermann G, Kinoshita T, Klein Goldewijk K,

2366 Riahi K, Shevliakova E, Smith S, Stehfest E, Thomson A, Thornton P, van Vuuren DP,

2367 Wang YP (2011) Harmonization of land-use scenarios for the period 1500–2100: 600

2368 years of global gridded annual land-use transitions, wood harvest, and resulting secondary

2369 lands. *Climatic Change* 109:117–161. doi: 10.1007/s10584–011–0153–2.

2370 Hurtt GC, Pacala SW, Moorcroft PR, Caspersen J, Shevliakova E, Houghton RA, Moore 3rd

2371 B (2002) Projecting the future of the U.S. carbon sink. *Proc Nat Acad Sci USA* 99:1389–

2372 1394.

2373 Izumi T, Ramankutty N (2016) Changes in yield variability of major crops for 1981–2010

2374 explained by climate change. *Environ Res Lett* 11(3):034003. doi: 10.1088/1748–

2375 9326/11/3/034003.

2376 Intergovernmental Panel on Climate Change (IPCC) (2014): Summary for Policymakers. In:

2377 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to

2378 the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker  
2379 TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V.  
2380 Midgley PM (eds.). Cambridge University Press, Cambridge, United Kingdom and New  
2381 York, NY USA.

2382 Ioffe G, Nefedova T, deBeurs K (2012) Land Abandonment in Russia. *Eurasian Geography  
2383 and Economics* 53(4):527–549. doi: 10.2747/1539–7216.53.4.527.

2384 Ioffe G, Nefedova T, deBeurs K (2014) Agrarian transformation in the Russian breadbasket:  
2385 contemporary trends as manifest in Stavropol'. *Post-Soviet Affairs* 30(6):441–463. doi:  
2386 10.1080/1060586X.2013.858509.

2387 Ivanov VA, Ivanova GA, Korchunov NA, Moskalchenko SA, Ponomarev EI (2011)  
2388 Correlation of forest fire occurrence with disturbance level of forest territories in the  
2389 Lower Angara region. *Forestry*, 1:39–41 (In Russian).

2390 Jacob T, Wahr J, Tad Pfeffer W, Swenson S (2012) Recent contributions of glaciers and ice  
2391 caps to sea level rise. *Nature Geoscience* 482:514–518. doi: 10.1038/nature10847.

2392 Jacobson M, Nghiem SV, Sorichetta A, Whitney N (2015) Ring of Impact from the Mega-  
2393 Urbanization of Beijing between 2000 and 2009. *J Geophys Res Atmos* 120(12). doi:  
2394 10.1002/2014JD023008.

2395 Jiang Y, Zhuang Q, Schaphoff S, Sitch S, Sokolov A, Kicklighter D, Melillo J (2012)  
2396 Uncertainty analysis of vegetation distribution in the northern high latitudes during the  
2397 21st century with a dynamic vegetation model. *Ecology and Evolution* 2(3):593–614. doi:  
2398 10.1002/ece3.85.

2399 Jiang Y, Zhuang Q, Sitch S, O'Donnell JA, Kicklighter D, Sokolov A, Melillo J (2016)  
2400 Importance of soil thermal regime in terrestrial ecosystem carbon dynamics in the  
2401 circumpolar north. *Global and Planetary Change* 142:28–40. doi:  
2402 10.1016/j.gloplacha.2016.04.011.

2403 Jin H, Li S, Cheng G, Shaoling W, Li X (2000) Permafrost and climatic change in China.

2404 *Glob and Planet Change* 26(4):387–404. doi: 10.1016/S0921-8181(00)00051-5.

2405 Jin HJ, Chang XL, Wang SL (2007) Evolution of permafrost on the Qinghai-Xizang (Tibet)

2406 Plateau since the end of the late Pleistocene. *J Geophys Res* 112:F02S09. doi:

2407 10.1029/2006JF000521.

2408 John R, Chen J, Kim Y, Ouyang Z, Xiao J, Park H, Shao C, Zhang Y, Amarjargal A, Qi J

2409 (2016) Differentiating anthropogenic modification and precipitation-driven change on

2410 vegetation productivity on the Mongolian Plateau. *Landscape Ecology* 31:547–566.

2411 John R, Chen J, Noormets A, Xiao X, Xu J, Lu N, Chen S (2013a) Modeling gross primary

2412 production in semi-arid Inner Mongolia using MODIS imagery and eddy covariance data.

2413 *Intern J Remote Sensing* 34(8):2829–2857. doi: 10.1080/01431161.2012.746483.

2414 John R, Chen J, Ouya, Z Xiao J, Becker R, Samanta A, Ganguly S, Yuan W, Batkhishig O

2415 (2013b) Vegetation response to extreme climate events on the Mongolian Plateau from

2416 2000–2010. *Environ Res Lett* 8:035033. doi:10.1088/1748-9326/8/3/035033.

2417 Jones AD, Collins WD, Edmonds J, Torn MS, Janetos A, Calvin KV, Thomson A, Chini LP,

2418 Mao J, Shi X, Thornton P, Hurt GC, Wise M (2013) Greenhouse gas policy influences

2419 climate via direct effects of land-use change. *J Climate* 26(11):3657–3670. doi:

2420 10.1175/JCLI-D-12-00377.1.

2421 Kantzas E, Lomas M, Quegan S (2013) Fire at high latitudes: Data-model comparisons and

2422 their consequences. *Global Biogeochem Cycles* 27(3):677–691. doi:10.1002/gbc.20059.

2423 Karl TR, Arguez A, Huang B, Lawrimore JH, McMahon JR, Menne MJ, Peterson TC, Vose

2424 RS, Zhang H-M (2015) Possible artifacts of data biases in the recent global surface

2425 warming hiatus. *Science*, 348(6242):1469–1472. doi: 10.1126/scienceaaa5632.

2426 Karthe D, Chalov S, Kasimov N, Kappas M (2015). Water and Environment in the Selenga-  
2427 Baikal Basin. Ibidem-Publisher, Stuttgart, Germany, ISSN: 1614-4716, ISBN-13: 978-3-  
2428 8382-0853-4.

2429 Kasischke ES, Bergen K, Fennimore R, Sotelo F, Stephens G, Janetos A, Shugart HH (1999)  
2430 Satellite imagery gives clear picture of Russia's boreal forest fires. *EOS* 80(13):141-147.  
2431 doi: 10.1029/99EO00094.

2432 Kattsov VM, Meleshko VP, Khlebnikova EI, Shkolnik IM (2012) Assessment of climate  
2433 impacts on agriculture in Russia over the first half of the 21st century: Current  
2434 opportunities provided by numerical modelling. *Agrophysics* 3:22-30.

2435 Kazstat (2014). Agriculture, Forestry and Fishing in Kazakhstan in 1990-2014 (Sel'skoe,  
2436 Lesnoe i Rybnoe Hozjajstvo Kazahstana v 1990-2014). A set of statistical yearbooks for  
2437 1990-2014. Agency of Statistics of Kazakhstan, Almaty.

2438 Keenleyside C, Tucker GM (2010) Farmland Abandonment in the EU: An Assessment of  
2439 Trends and Prospects. Report Prepared for WWF. Institute for European Environmental  
2440 Policy, London.

2441 Kelley CP, Mohtadi S, Cane MA, Seager R, Kushnir Y (2015) Climate change in the Fertile  
2442 Crescent and implications of the recent Syrian drought. *Proc Nat Acad Sci USA*  
2443 112(11):3241-3246.

2444 Kharuk VI, Dvinskaya ML, Petrov IA, Im ST, Ranson KJ (2016) Larch forests of Middle  
2445 Siberia: long-term trends in fire return intervals. *Reg Environ Change*. doi:  
2446 10.1007/s10113-016-0964-9.

2447 Kharuk VI, Im ST, Petrov IA, Golyukov AS, Ranson KJ, Yagunov MN (2017a) Climate-  
2448 induced mortality of Siberian pine and fir in the Lake Baikal Watershed, Siberia. *Forest*  
2449 *Ecology and Management* 384:191-199. <http://dx.doi.org/10.1016/j.foreco.2016.10.050>.

2450 Kharuk VI, Im ST, Petrov IA, Ranson KJ, Yagunov MN (2017b) Climate-Induced Northerly  
2451 Expansion of Siberian Silkmoth Range. *Forests*. 8 301 ; doi:10.3390/f8080301.

2452 Khon VCh, Mokhov II (2012) The Hydrological Regime of Large River Basins in Northern  
2453 Eurasia in the XX–XXI Centuries. *Water Resources*, 39(1):1–10. doi:  
2454 10.1134/S0097807812010058.

2455 Khromova T, Nosenko G, Kutuzov S, Muraviev A, Chernova L (2014) Glacier area changes  
2456 in Northern Eurasia. *Environ Res Lett* 9(1):015003. doi: 10.1088/1748–9326/9/1/015003.

2457 Khrustalev LN, Davidova IV (2007) Forecast of climate warming and account of it at  
2458 estimation of foundation reliability for buildings in permafrost zone. *Earth Cryosphere*  
2459 11(2):68–75. (in Russian).

2460 Khrustalev LN, Parmuzin SY, Emelyanova LV (2011) Reliability of northern infrastructure in  
2461 conditions of changing climate. University Book Press, Moscow.

2462 Khvostikov S, Venevsky S, Bartalev S (2015) Regional adaptation of a dynamic global  
2463 vegetation model using a remote sensing data derived land cover map of Russia. *Environ*  
2464 *Res Lett*:10(12):125007.

2465 Kicklighter DW, Cai Y, Zhuang Q, Parfenova EI, Paltsev S, Sokolov AP, Melillo JM, Reilly  
2466 JM, Tchebakova NM, Lu X (2014) Potential influence of climate-induced vegetation shifts  
2467 on future land use and associated land carbon fluxes in Northern Eurasia. *Environ Res Lett*  
2468 9:035004. doi: 10.1088/1748–9326/9/3/035004.

2469 Kicklighter DW, Hayes DJ, McClelland JW, Peterson BJ, McGuire AD, Melillo JM (2013)  
2470 Insights and issues with simulating terrestrial DOC loading of arctic river networks.  
2471 *Ecological Applications* 23(8):1817–1836. doi: 10.1890/11–1050.1.

2472 Kim H-S, Maksyutov S, Glagolev MV, Machida T, Patra PK, Sudo K, Inoue G (2011)  
2473 Evaluation of methane emissions from West Siberian wetlands based on inverse modeling.  
2474 *Environ Res Lett* 6(3):035201. doi:10.1088/1748–9326/6/3/035201.

2475 Kirschke S, Bousquet P, Ciais P, Saunois M, Canadell JG, Dlugokencky EJ, Bergamaschi P,  
2476 Bergmann D, Blake DR, Bruhwiler L, Cameron-Smith P, Castaldi S, Chevallier F, Feng L,  
2477 Fraser A, Heimann M, Hodson EI, Houweling S, Josse B, Fraser PJ, Krummel PB,  
2478 Lamarque JF, Langenfelds RL, Le Quéré C, Naiket V, *al.* (2013) Three decades of global  
2479 methane sources and sinks. *Nature Geoscience* 6:813–823. doi: 10.1038/NGEO1955.

2480 Klehmet K, Geyer B, Rockel B (2013) A regional climate model hindcast for Siberia: analysis  
2481 of snow water equivalent. *The Cryosphere* 7:1017–1034. doi: 10.5194/tc-7-1017-2013,

2482 Klein I, Gessner U, Kuenzer C (2012) Regional land cover mapping and change detection in  
2483 Central Asia using MODIS time-series. *Applied Geography* 35(1–2):219–234.

2484 Knorn J, Kuemmerle T, Szabo A, Hostert P (2012) Forest restitution and protected area  
2485 effectiveness in post-socialist Romania. *Biological Conservation*, 146(1):204–212. doi:  
2486 10.1016/j.biocon.2011.12.020.

2487 Koch N, Valiyev A (2015) Urban boosterism in closed contexts: spectacular urbanization and  
2488 second-tier mega-events in three Caspian capitals. *Eurasia Geography and Economics*  
2489 56(5):575–598. doi: 10.1080/15387216.2016.1146621.

2490 Kopáček J, Posch M (2011) Anthropogenic nitrogen emissions during the Holocene and their  
2491 possible effects on remote ecosystems. *Global Biogeochem Cycles* 25(2):GB2017. doi:  
2492 10.1029/2010GB003779.

2493 Kopáček J, Posch M, Hejzlar J, Oulehle F, Volková A (2012) An elevation-based regional  
2494 model for interpolating sulphur and nitrogen deposition. *Atmospheric*  
2495 *Environment* 50:287–296. doi: 10.1016/j.atmosenv.2011.12.017

2496 Kopačková V, Misurec J, Lhotakova Z, Oulehle F, Albrechtová J (2014) Using multi-date  
2497 high spectral resolution data to assess physiological status of macroscopically undamaged  
2498 foliage on a regional scale. *Int J Appl Earth Obs Geoinform* 27:169–186.

2499 Kopačková V, Lhotáková Z, Oulehle F, Albrechtová J. (2015) Assessing forest health via  
2500 linking the geochemical properties of soil profile with the biochemical parameters of  
2501 vegetation. *Int J Environ Sci Technol* 12(6):1987–2002. doi: 10.1007/s13762–014–0602–  
2502 3.

2503 Koven CD, Lawrence DM, Riley WJ (2015) Permafrost carbon-climate feedback is sensitive  
2504 to deep soil carbon decomposability but not deep soil nitrogen dynamics. *Proc. Nat. Acad.  
2505 Sci. USA* 112(12):3752–3757. doi: 10.1073/pnas.1415123112.

2506 Koven CD, Ringeval B, Friedlingstein P, Ciais P, Cadule P, Khvorostyanov D, Krinner G,  
2507 Tarnocai C (2011) Permafrost carbon-climate feedbacks accelerate global warming. *Proc  
2508 Nat Acad Sci USA* 108(36):14769–14774. doi: 10.1073/pnas.1103910108.

2509 Kozharinov AV, Borisov PV (2013) Distribution of Oak Forests in Eastern Europe over the  
2510 Last 13000 Years. *Contemporary Problems of Ecology*, 6(7):755–760. Pleiades Publishing,  
2511 Ltd. (original paper was published in *Lesovedenie* 2012 (5):22–28 in Russian).

2512 Kraemer R, Prishchepov AV, Müller D, Kuemmerle T, Radeloff VC, Dara A, Terekhov A,  
2513 Frühauf M (2015) Long-term agricultural land-cover change and potential for cropland  
2514 expansion in the former Virgin Lands area of Kazakhstan. *Environ Res Lett* 10(5):054012.  
2515 doi: 10.1088/1748–9326/10/5/054012.

2516 Krylov A, McCarty JL, Potapov P, Loboda T, Tyukavina A, Turubanova S, Hansen MC  
2517 (2014) Remote sensing estimates of stand-replacement fires in Russia, 2002–2011.  
2518 *Environ Res. Lett* 9(10):105007. doi: 10.1088/1748–9326/9/10/105007.

2519 Krysanova V, Wortmann M, Bolch T, Merz B, Duethmann D, Walter J, Huang S, Tong J.,  
2520 Buda S, Kundzewicz (2015) Analysis of current trends in climate parameters, river  
2521 discharge and glaciers in the Aksu River basin (Central Asia). *Hydrological Sciences  
2522 Journal* 60(4):566–590.

2523 Kuchment LS, Gelfan AN, Demidov VN (2011) Modeling of the hydrological cycle of a  
2524 forest river basin and hydrological consequences of forest cutting. *The Open Hydrology  
2525 Journal* 5:9–18.

2526 Kuemmerle T, Baskin L, Leitão P, Prishchepov AV, Thonicke K, Radeloff VC (2014)  
2527 Potential impacts of oil and gas development and climate change on migratory reindeer  
2528 calving grounds across the Russian Arctic. *Diversity and Distributions*, 20(4): 416–429.  
2529 doi: 10.1111/ddi.12167.

2530 Kuemmerle T, Chaskovskyy O, Knorn J, Radeloff VC, Kruhlov I, Keeton WS, Hostert P  
2531 (2009) Forest cover change and illegal logging in the Ukrainian Carpathians in the  
2532 transition period from 1988 to 2007. *Remote Sensing of Environment* 113(6):1194–1207.  
2533 doi: 10.1016/j.rse.2009.02.006.

2534 Kuemmerle T, Hostert P, Radeloff VC, van der Linden S, Perzanowski K, Kruhlov I (2008)  
2535 Cross-border comparison of post-socialist farmland abandonment in the Carpathians.  
2536 *Ecosystems*, 11(4):614–628. doi: 10.1007/s10021–008–9146-z.

2537 Kuemmerle T, Olofsson P, Chaskovskyy O, Baumann M, Ostapowicz K, Woodcock C,  
2538 Houghton RA, Hostert P, Keeton W, Radeloff VC (2011b) Post-Soviet farmland  
2539 abandonment, forest recovery, and carbon sequestration in western Ukraine. *Global  
2540 Change Biology*, 17(3):1335–1349. doi: 10.1111/j.1365–2486.2010.02333.x.

2541 Kuemmerle T, Perzanowski K, Akcakaya HR, Beaudry F, van Deelen TR, Parnikoza I,  
2542 Khoyetskyy P, Waller DM, Radeloff VC (2011a) Cost-effectiveness of different  
2543 conservation strategies to establish a European bison metapopulation in the Carpathians. *J.  
2544 Appl. Ecol* 48(2):317–329. doi: 10.1111/j.1365–2664.2010.01954.x.

2545 Kukavskaya EA, Buryak LV, Ivanova GA, Conard SG, Kalenskaya OP, Zhila SV, McRae DJ  
2546 (2013a) Influence of logging on the effects of wildfire in Siberia, *Environ Res Lett*  
2547 8(4):045034. doi: 10.1088/1748–9326/8/4/045034.

2548 Kukavskaya EA, Buryak LV, Shvetsov EG, Conard SG, Kalenskaya OP (2016) The impact of  
2549 increasing fire frequency on forest transformations in southern Siberia. *Forest Ecology and*  
2550 *Management* 382:225–235. <http://dx.doi.org/10.1016/j.foreco.2016.10.015>.

2551 Kukavskaya EA, Soja AJ, Petkov AP, Ponomarev EI, Ivanova GA, Conard SG (2013b) Fire  
2552 emissions estimates in Siberia: Evaluation of uncertainties in area burned, land cover, and  
2553 fuel consumption. *Canadian J Forest Res* 43(5):493–506. doi: 10.1139/cjfr-2012-0367.

2554 Kukuev YA., Krankina ON, Harmon ME (1997) The forest inventory system in Russia: A  
2555 wealth of data for western researchers. *J Forestry*, 95:15–20.

2556 Kumpula T, Pajunen A, Kaarlejärvi E, Forbes BC, Stammler F (2011) Land use and land  
2557 cover change in Arctic Russia: Ecological and social implications of industrial  
2558 development. *Glob. Environ. Change* 21(2):550–562. doi:  
2559 [10.1016/j.gloenvcha.2010.12.010](http://dx.doi.org/10.1016/j.gloenvcha.2010.12.010).

2560 Kundzewicz ZW, Merz B, Vorogushyn S, Hartmann H, Duethmann D, Wortmann M, Huang  
2561 S, Su B, Jiang T, Krysanova V (2015) Analysis of changes in climate and river discharge  
2562 with focus on seasonal runoff predictability in the Aksu River Basin. *Hydrological*  
2563 *Sciences Journal* 60(4):501–516.

2564 Kurganova I, Lopes de Gerenu V, Kuzyakov Y (2015) Large-scale carbon sequestration in  
2565 post-agrogenic ecosystems in Russia and Kazakhstan. *CATENA*, 133:461–466. doi:  
2566 [10.1016/j.catena.2015.06.002](http://dx.doi.org/10.1016/j.catena.2015.06.002).

2567 Kurganova I, Lopes de Gerenu V, Six J, Kuzyakov Y (2014) Carbon cost of collective  
2568 farming collapse in Russia. *Global Change Biology* 20(3):938–947. doi:  
2569 [10.1111/gcb.12379](http://dx.doi.org/10.1111/gcb.12379).

2570 Kutuzov S., Lavrentiev I, Vasilenko E, Macheret YY, Petrakov DA, Popov GV (2015)  
2571 Estimation of the greater Caucasus glaciers volume, using radio-echo sounding data and  
2572 modelling. *Earth's Cryosphere* XIX(1):78–88.

2573 Kutuzov S, Shahgedanova M (2009) Changes in the Extent of Glaciers in the Eastern Terskey  
2574 Alatoo, the Central Tien-Shan, in Response to Climatic Fluctuations in Between the End of  
2575 the 19<sup>th</sup> and the Beginning of the 21<sup>st</sup> Century. *Global and Planetary Change* 69(1–2):59–  
2576 70.

2577 Lambrecht A, Mayer C, Hagg W, Popovnin V, Rezepkin A, Lomidze N, Svanadze D (2011)  
2578 A comparison of glacier melt on debris-covered glaciers in the northern and southern  
2579 Caucasus. *The Cryosphere* 5:525–538.

2580 Lammers R B, Pundsack JW, Shiklomanov AI (2007) Variability in river temperature,  
2581 discharge, and energy flux from the Russian pan-Arctic landmass. *J Geophys Res* 112:  
2582 G04S59. doi:10.1029/2006JG000370.

2583 Lapenit A, Shvidenko A, Schepaschenko D, Nilsson S, Aiyer A, (2005) Acclimation of  
2584 Russian forests to recent change in climate. *Global Change Biology* 11(12):2090–2102.  
2585 doi: 10.1111/j.1365–2486.2005.001069.x.

2586 Lebed L, Qi J, Heilman P (2012) An ecological assessment of pasturelands in the Balkhash  
2587 area of Kazakhstan with remote sensing and models. *Environ Res Lett* 7(2):025203. doi:  
2588 10.1088/1748–9326/7/2/025203.

2589 LeGrande AN, Schmidt GA, Shindell DT, Field CV, Miller RL, Koch DM, Faluvegi G,  
2590 Hoffmann G (2006) Consistent simulations of multiple proxy responses to an abrupt  
2591 climate change event. *Proc Natl Acad Sci* 103(4):837–842. doi: 10.1073/pnas.0510095103.

2592 Le Quéré C, Moriarty R , Andrew RM, Canadell JG, Sitch S, Korsbakken JI, Friedlingstein  
2593 P, Peters GP, Andres RJ, Boden TA , Houghton RA, House JI, Keeling RF, Tans P, Arneth  
2594 A, Bakker DCF, Barbero L, Bopp L, Chang J , Chevallier F, Chini LP, Ciais P, Fader M,  
2595 Feely RA, Gkritzalis T, Harris I, Hauck J, Ilyina T, Jain AK, Kato E, *et al.* (2015) Global  
2596 Carbon Budget 2015. *Earth System Science Data*, 7:349–396. doi: 10.5194/essd-7–349–  
2597 2015.

2598 Lei G (2011) Impacts of Natural Disaster to Agricultural Development in Heilongjiang  
2599 Province. *J Agrotech Economics* 2011(4):38–39.

2600 Lerman Z, Csaki C, Feder G (2004) Agriculture in transition: land policies and evolving farm  
2601 structures in post-Soviet countries. Lexington Books, Lanham, Boulder, New York,  
2602 Toronto, Oxford.

2603 Li C, Qi J., Yang L, Wang S, Yang W, Zhu G, Zou S, Zhang F (2014) Regional vegetation  
2604 dynamics and its response to climate change—a case study in the Tao River Basin in  
2605 Northwestern China. *Environ Res Lett* 9(12):125003.

2606 Li Q, Xu L, Pan X, Zhang L, Li C, Yang N, Qi J (2016) Modeling phenological responses of  
2607 Inner Mongolia grassland species to regional climate change. *Environ Res Lett*  
2608 11(1):015002.

2609 Liefert WM, Liefert O, Vocke G, Allen EW (2010) Former Soviet Union Region to Play  
2610 Larger Role in Meeting World Wheat Needs. *Amber Waves*. Retrieved from  
2611 <http://ideas.repec.org/a/ags/uersaw/121958.html>.

2612 Lieskovský J, Bezák P, Špulerová J, Lieskovský T, Koleda P, Dobrovodská M, Bürgi M,  
2613 Gimmi U (2015) The abandonment of traditional agricultural landscape in Slovakia –  
2614 Analysis of extent and driving forces. *Journal of Rural Studies* 37:75–84. doi:  
2615 10.1016/j.jrurstud.2014.12.007.

2616 Linsbauer A, Paul F, Haeberli W (2012) Modeling glacier thickness distribution and bed  
2617 topography over entire mountain ranges with glabtop: Application of a fast and robust  
2618 approach, *J Geophys Res Earth Surf* 117(3):1–17. doi: 10.1029/2011JF002313.

2619 Lioubimtseva E, Henebry GM (2009) Climate and environmental change in arid Central Asia:  
2620 Impacts, vulnerability, and adaptations. *J Arid Environ* 73(11):963–977. doi:  
2621 10.1016/j.jaridenv.2009.04.022.

2622 Lioubimtseva E, Henebry GM (2012) Grain production trends in Russia, Ukraine and  
2623 Kazakhstan: New opportunities in an increasingly unstable world? *Frontiers of Earth*  
2624 *Science* 6(2):157–166. doi: 10.1007/s11707–012–0318–y.

2625 Liu Y, Liu Y, Chen Y, Long H (2010) The process and driving forces of rural hollowing in  
2626 China under rapid urbanization. *J Geograph Sci* 20(6):876–888. doi: 10.1007/s11442–010–  
2627 0817–2.

2628 Liu Y, Zhuang Q, Chen M, Pan Z, Tchebakova N, Sokolov A, Kicklighter D, Melillo J, Sirin  
2629 A, Zhou G, He Y, Chen J, Bowling L, Miralles D, Parfenova E (2013) Response of  
2630 evapotranspiration and water availability to changing climate and land cover on the  
2631 Mongolian Plateau during the 21st century. *Global and Planetary Change* 108:85–99. doi:  
2632 10.1016/j.gloplacha.2013.06.008.

2633 Liu Y, Zhuang Q, Miralles D, Pan Z, Kicklighter D, Zhu Q, He Y, Chen J, Tchebakova N,  
2634 Sirin A, Niyogi D, Melillo J (2015) Evapotranspiration in Northern Eurasia: impact of  
2635 forcing uncertainties on terrestrial ecosystem model estimates. *J Geophys Res–  
2636 Atmospheres* 120(7):2647–2660. doi: 10.1002/2014JD022531.

2637 Liu Y, Zhuang Q, Pan Z, Miralles D, Tchebakova N, Kicklighter D, Chen J, Sirin A, He Y,  
2638 Zhou G, Melillo J (2014) Response of evapotranspiration and water availability to the  
2639 changing climate in Northern Eurasia. *Climatic Change* 126(3):413–427. doi:  
2640 10.1007/s10584–014–1234–9.

2641 Loboda TV, Chen D (2016) Spatial distribution of young forests and carbon fluxes within  
2642 recent disturbances in Russia. *Global Change Biology*. doi:10.1111/gcb.13349.

2643 Loboda TV, Csiszar IA (2007) Assessing the risk of ignition in the Russian Far East within a  
2644 modeling framework of fire threat. *Ecological Applications* 17 (3):791–805. doi:  
2645 10.1890/05–1476.

2646 Loboda TV, Krankina ON, Kurbanov EA, Savin I, Hall JV (2016) Land management and  
2647 impact of 2010 extreme drought event on agricultural and ecological systems of European  
2648 Russia. In: Gutman G, and Radeloff V (eds) Land-cover and land-use change in Eastern  
2649 Europe 1990–2010: Impacts of the breakup of the Soviet Union.

2650 Loboda TV, Zhang Z, O'Neal KJ, Sun G, Csiszar IA, Shugart HH, Sherman NJ (2012)  
2651 Reconstructing disturbance history using satellite-based assessment of the distribution of  
2652 land cover in the Russian Far East. *Remote Sensing of Environment* 118:241–248. doi:  
2653 10.1016/j.rse.2011.11.022.

2654 Loranty MM, Berner LT, Goetz SJ, Jin Y, Randerson JT (2014) Vegetation controls on  
2655 northern high latitude snow-albedo feedback: observations and CMIP5 model simulations.  
2656 *Global Change Biology* 20(2):594–606. doi: 10.1111/gcb.12391.

2657 Lu N, Wilske B, Ni J, John R, Chen J (2009a) Climate change in Inner Mongolia from 1955  
2658 through 2005. *Environ Res Lett* 4:045006. doi:10.1088/1748–9326/4/4/045006.

2659 Lu Y, Zhuang Q, Zhou G, Sirin A, Melillo J, Kicklighter D (2009b) Possible decline of the  
2660 carbon sink in the Mongolian Plateau during the 21<sup>st</sup> century. *Environ Res Lett*  
2661 4(4):045023. doi: 10.1088/1748–9326/4/4/045023.

2662 Lu Z, Streets DG, Zhang Q, Wang S, Carmichael GR, Cheng YF, Wei C, Chin M, Diehl T,  
2663 Tan Q (2010) Sulfur dioxide emissions in China and sulfur trends in East Asia since 2000.  
2664 *Atmos Chem Phys* 10(13):6311–6331. doi: 10.5194/acp-10–6311–2010.

2665 Lugina KM, Groisman PY, Vinnikov KY, Koknaeva VV, Speranskaya NA (2006) Monthly  
2666 surface air temperature time series area-averaged over the 30-degree latitudinal belts of the  
2667 globe, 1881–2005. In Trends Online: A Compendium of Data on Global Change. Carbon  
2668 Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of  
2669 Energy, Oak Ridge, Tennessee, U.S.A. doi: 10.3334/CDIAC/cli.003 (on October 28, 2017  
2670 has been available at <http://cdiac.ess-dive.lbl.gov/trends/temp/lugina/lugina.html>).

2671 Lupo AR, Oglesby RJ, Mokhov II (1997) Climatological features of blocking anticyclones: A  
2672 study of Northern Hemisphere CCM1 model blocking events in present-day and double  
2673 CO<sub>2</sub> concentration atmospheres. Climate Dyn 13(3):181–195. doi:  
2674 10.1007/s003820050159.

2675 Lupo AR, Mokhov II, Akperov MG, Chernokulsky AV, Hussain A (2012) A dynamic  
2676 analysis of the role of the planetary and synoptic scale in the summer of 2010 blocking  
2677 episodes over the European part of Russia. *Advances in Meteorology* 2012:584257.

2678 MacDougall AH, Knutti R (2016) Projecting the release of carbon from permafrost soils using  
2679 a perturbed parameter ensemble modeling approach. *Biogeosciences* 13:2123–2136. doi:  
2680 10.5194/bg-13–2123–2016.

2681 Macias-Fauria M, Forbes BC, Zetterberg P, Kumpula T (2012) Eurasian Arctic greening  
2682 reveals teleconnections and the potential for structurally novel ecosystems. *Nature Climate  
2683 Change* 2:613–618. doi: 10.1038/nclimate1558.

2684 Magliocca NR, Brown DG, Ellis EC (2013) Exploring agricultural livelihood transitions with  
2685 an agent-based virtual laboratory: global forces to local decision-making. *PLoS One*.  
2686 8(9):e73241. doi:10.1371/journal.pone.0073241.

2687 Maksyutov S, Takagi H, Valsala VK, Saito M, Oda T, Saeki T, Belikov DA, Saito R, Ito A,  
2688 Yoshida Y, Morino I, Uchino O, Andres RJ, Yokota T (2013) Regional CO<sub>2</sub> flux estimates  
2689 for 2009–2010 based on GOSAT and ground-based CO<sub>2</sub> observations. *Atmospheric  
2690 Chemistry and Physics*, 13:9351–9373.

2691 Malevsky-Malevich SP, Molkentin EK, Nadyozhina ED, Shklyarevich OB (2008) An  
2692 assessment of potential change in wildfire activity in the Russian boreal forest zone  
2693 induced by climate warming during the twenty-first century. *Climatic Change* 86(3):463–  
2694 474. doi: 10.1007/s10584–007–9295–7.

2695 Mannig B, Müller M, Starke E, Merkenschlager C, Mao W, Zhi X, Podzun R, Jacob D, Paeth  
2696 H (2013) Dynamical downscaling of climate change in Central Asia. *Global and Planetary*  
2697 *Change* 110:26–39.

2698 Marchenko SS, Gorbunov AP, Romanovsky VE (2007) Permafrost warming in the Tien Shan  
2699 Mountains, Central Asia. *Global and Planetary Change*, 56(3–4):311–327. doi:  
2700 10.1016/j.gloplacha.2006.07.023.

2701 Markov ML (1994) The Role of Cryogenic Barrage in the Formation of River Discharge in  
2702 Permafrost Areas. *Meteorology and Hydrology* 1994(2):98–104 (in Russian).

2703 Markov ML (2003) Spatial-temporal dynamic of surface and ground water interaction. *Proc.*  
2704 *State Hydrolog Inst Hydrometeoizdat* 25:90–104 (in Russian).

2705 Mathieson RS (1979) Japan's role in Soviet economic growth: transfer of technology since  
2706 1965. Praeger Publishers New York.

2707 Mátyás C, Sun G (2014) Forests in a water limited world under climate change. *Environ Res*  
2708 *Lett* 9:085001. doi: 10.1088/1748–9326/9/8/085001.

2709 McCarty JL, Ellicott EA, Romanenkov V, Rukhovitch D, Koroleva P (2012), Multi-year  
2710 black carbon emissions from cropland burning in the Russian Federation. *Atmos Environ*  
2711 63:223–238. doi: 10.1016/j.atmosenv.2012.08.053.

2712 McCarty JL, Krylov A, Prishchepov AV, Banach DM, Tyukavina A, Potapov P, Turubanova  
2713 S (2017). Agricultural fires in European Russia, Belarus, and Lithuania, and their impact  
2714 on air quality, 2002–2012. In: Gutman G, Radeloff V (eds) *Land-cover and land-use*  
2715 *change in Eastern Europe after the collapse of the Soviet Union in 1991*. Springer,  
2716 Switzerland. doi: 10.1007/978-3-319–42638–9\_9.

2717 McClelland, JW, Dery SJ, Peterson BJ, Holmes RM, Wood EF (2006), A pan-arctic  
2718 evaluation of changes in river discharge during the latter half of the 20th century, *Geophys*  
2719 *Res Lett* 33: L06715. doi:10.1029/2006GL025753.

2720 McClelland JW, Holmes RM, Peterson BJ, Stieglitz M (2004) Increasing river discharge in  
2721 the Eurasian Arctic: Consideration of dams, permafrost thaw, and fires as potential agents  
2722 of change. *J Geophys Res* 109(D18):D18102. doi: 10.1029/2004JD004583.

2723 McGuire AD, Hayes DJ, Kicklighter DW, Manizza M, Zhuang Q, Chen M, Follows MJ,  
2724 Gurney KR, McClelland JW, Melillo JM, Peterson BJ Prinn RG (2010) An analysis of the  
2725 carbon balance of the Arctic Basin from 1997 to 2006. *Tellus B* 62(5):455–474. doi:  
2726 10.1111/j.1600-0889.2010.00497.x.

2727 Melillo JM, Lu X, Kicklighter DW, Reilly JM, Cai Y, Sokolov AP (2016) Protected areas'  
2728 role in climate-change mitigation. *Ambio* 45(2):133–145. doi: 10.1007/s13280-015-0693-  
2729 1.

2730 Melillo JM, Reilly JM, Kicklighter DW, Gurgel AC, Cronin TW, Paltsev S, Felzer BS, Wang  
2731 X, Sokolov AP, Schlosser CA (2009) Indirect emissions from biofuels: how important?  
2732 *Science* 326(5958):1397–1399. doi: 10.1126/science.1180251.

2733 Meredith EP, Semenov VA, Maraun D, Park W, Chernokulsky AV (2015) Crucial role of  
2734 Black Sea warming in amplifying the 2012 Krymsk precipitation extreme. *Nature  
2735 Geoscience* 8(8):615–619. doi: 10.1038/ngeo2483.

2736 Meyfroidt P, Schierhorn F, Prishchepov AV, Müller D, Kuemmerle T (2016) Drivers,  
2737 constraints and trade-offs associated with recultivating abandoned cropland in Russia,  
2738 Ukraine and Kazakhstan. *Global Environmental Change* 37:1–15. doi:  
2739 10.1016/j.gloenvcha.2016.01.003.

2740 Miao C, Duan Q, Sun Q, Huang Y, Kong D, Yang T, Ye A, Di Z, Gong W (2014)  
2741 Assessment of CMIP5 climate models and projected temperature changes over Northern  
2742 Eurasia. *Environ Res Lett* 9(5): 055007.

2743 Mišurec J, Kopačková V, Lhotáková Z, Campbell P, Albrechtová J (2016) Detection of  
2744 spatio-temporal changes of Norway spruce forest stands in Ore Mountains using Landsat

2745 time series and airborne hyperspectral imagery. *Remote Sens* 8(2):92. doi:  
2746 10.3390/rs8020092.

2747 Mokhov II, Akperov MG, Prokofyeva MA, Timazhev AV, Lupo AR, Le Treut H (2013a)  
2748 Blockings in the Northern Hemisphere and Euro-Atlantic Region: Estimates of changes  
2749 from reanalysis data and model simulations. *Doklady Earth Sci* 449(2):430–433. doi:  
2750 10.1134/S1028334X13040144.

2751 Mokhov II, Semenov VA, Khon VCh, Pogarsky FA (2013b) Change of the sea ice extent in  
2752 the Arctic and the associated climate effects: Detection and simulation. *Ice and Snow*  
2753 2013(2):53–62 (in Russian with English Summary and Figure captions).  
2754 doi: 10.15356/2076–6734–2013–2–53–62

2755 Monier E, Kicklighter D, Sokolov A, Zhuang Q, Sokolik I, Lawford R, Kappas M, Paltsev S,  
2756 Groisman P (2017) A review of and perspectives on global change modeling for Northern  
2757 Eurasia. *Environ. Res. Lett* 12 083001.

2758 Monier E, Sokolov A, Schlosser A, Scott J, Gao X (2013) Probabilistic projections of 21<sup>st</sup>  
2759 century climate change over Northern Eurasia. *Environ Res Lett* 8(4):045008. doi:  
2760 10.1088/1748–9326/8/4/045008.

2761 Motovilov Y, Gelfan A, (2013) Assessing runoff sensitivity to climate change in the Arctic  
2762 basin: empirical and modelling approaches. In: Gelfan A, Yang D, Gusev E, Kunstmann H  
2763 (eds) *Cold and Mountain Region Hydrological Systems Under Climate Change: Towards*  
2764 *Improved Projections*. IAHS Publications 360:105–112.

2765 Mukhortova L, Schepaschenko D, Shvidenko A, McCallum I, Kraxner F (2015) Soil  
2766 contribution to carbon budget of Russian forests. *Agricultural and Forest Meteorology*  
2767 200:97–108.

2768 Narama C, Kääb A, Duishonakunov M, Abdurakhmatov K (2010) Spatial variability of recent  
2769 glacier area changes in the Tien Shan Mountains, Central Asia, using Corona (~1970),

2770 Landsat (~2000), and ALOS (~2007) satellite data, *Glob Planet Change* 71:42–54.  
2771 doi:10.1016/j.gloplacha.2009.08.002.

2772 Narayan C, Fernandes PM, van Brusselen J, Schuck A (2007) Potential for CO<sub>2</sub> emissions  
2773 mitigation in Europe through prescribed burning in the context of the Kyoto Protocol.  
2774 *Forest Ecology and Management* 251(3):164–173. doi: 10.1016/j.foreco.2007.06.042.

2775 Nelson GC, Valin H, Sands RD, Havlík P, Ahammad H, Deryng D, Elliott J, Fujimori S,  
2776 Hasegawa T, Heyhoe E, Kyle P, Von Lampe M, Lotze-Campen H, Mason d’Croza D, van  
2777 Meijl H, van der Mensbrugghem D, Müller C, Popp A, Robertson R, Robinson S, Schmid  
2778 E, Schmitz C, Tabeau A, Willenbockel D (2014a) Climate change effects on agriculture:  
2779 Economic responses to biophysical shocks, *PNAS*, 111(9):3274–3279. doi:  
2780 10.1073/pnas.1222465110.

2781 Nelson GC, von der Mensbrugge D, Ahammad H, Blanc E, Calvin K, Hasegawa T, Havlik  
2782 P, Heyhoe E, Kyle P, Lotze-Campen H, von Lampe M, Mason d’Croz D, van Meijl H,  
2783 Müller C, Reilly J, Robertson R, Sands RD, Schmitz C, Tabeau A, Takahashi K, Valin H,  
2784 Willenbockel D (2014b) Agriculture and climate change in global scenarios: why don’t the  
2785 models agree. *Agricultural Economics* 45(1):85–101. doi: 10.1111/agec.12091.

2786 Newell JP, Simeone J (2014) Russia’s forests in a global economy: how consumption drives  
2787 environmental change. *Eurasian Geography and Economics* 55(1):37–70. doi:  
2788 10.1080/15387216.2014.926254.

2789 Newell JP, and Wilson E (2004) The Russian Far East. Friends of the Earth, Tokyo.

2790 Newson RL (1973) Response of a General Circulation Model of the Atmosphere to Removal  
2791 of the Arctic Ice-cap. *Nature* 241:39 – 40. doi: 10.1038/241039b0.

2792 Nghiêm SV, Balk D, Rodriguez E, Neumann G, Sorichetta A, Small C, Elvidge CD (2009)  
2793 Observations of Urban and Suburban Environments with Global Satellite Scatterometer  
2794 Data. *ISPRS J Photogr Remote Sens* 64:367–380. doi:10.1016/j.isprsjprs.2009.01.004.

2795 Nghiem, SV, Hall DK, Rigor IG, Li P, Neumann G (2014), Effects of Mackenzie River  
2796 discharge and bathymetry on sea ice in the Beaufort Sea, *Geophys Res Lett* 41: 873–879.  
2797 doi:10.1002/2013GL058956.

2798 Nghiem SV, Small C (2016) Synergistic use of multi-satellite sensors for mapping and  
2799 monitoring LCLUC across multi-scales in the time-space continuum, invited key-note  
2800 presentation. 2<sup>nd</sup> EARSeL SIG LU/LC and NASA LCLUC joint Workshop, Prague,  
2801 Czechia.

2802 Nikodemus O, Bell S, Grine I, Liepins I (2005) The impact of economic, social and political  
2803 factors on the landscape structure of the Vidzeme Uplands in Latvia. *Landscape and Urban*  
2804 *Planning* 70(1–2):57–67. doi: 10.1016/j.landurbplan.2003.10.005.

2805 Nosenko GA, Khromova TE, Rototaeva OV, Shahgedanova MV (2013) Glacier reaction to  
2806 temperature and precipitation change in Central Caucasus, 2001–2010. *Ice and Snow*  
2807 2013(1):26–33 (in Russian with English Summary).

2808 Novenko EY, Olchev AV (2015) Early Holocene vegetation and climate dynamics in the  
2809 central part of the East European Plain (Russia). *Quaternary International* 388:12–22. doi:  
2810 10.1016/j.quaint.2015.01.027.

2811 Novenko EY, Zyuganova IS, Olchev AV (2014) Application of the paleoanalog method for  
2812 prediction of vegetation dynamics under climate changes. *Doklady Biological Sciences*  
2813 457(1):228–232. doi: 10.1134/S0012496614040024.

2814 Ojima D, Chuluun T (2008) Policy changes in Mongolia: Implications for land use and  
2815 landscapes. In: Galvin K, Reid R, Behnke R, Hobb N (eds) *Fragmentation in Semi-Arid*  
2816 *and Arid Landscape: Consequences for Human and Natural Systems*, Springer, Dordrecht.

2817 Olchev AV, Deshcherevskaya OA, Kurbatova YA, Molchanov AG, Novenko EY, Pridacha  
2818 VB, Sazonova TA (2013a) CO<sub>2</sub> and H<sub>2</sub>O exchange in the forest ecosystems of southern

2819 taiga under climate changes. *Doklady Biological Sciences*, 450:173–176. doi:  
2820 10.1134/S0012496613030216.

2821 Olchev A, Novenko E, Desherevskaya O, Krasnorutskaya K, Kurbatova J (2009a) Effects of  
2822 climatic changes on carbon dioxide and water vapor fluxes in boreal forest ecosystems of  
2823 European part of Russia. *Environ Res Lett* 4(4):045007. doi: 10.1088/1748–  
2824 9326/4/4/045007.

2825 Olchev A, Radler K, Sogachev A, Panferov O, Gravenhorst G (2009b) Application of a three-  
2826 dimensional model for assessing effects of small clear-cuttings on radiation and soil  
2827 temperature. *Ecological Modelling* 220(21):3046–3056. doi:  
2828 10.1016/j.ecolmodel.2009.02.004.

2829 Olchev A, Volkova E, Karataeva T, Novenko E (2013b) Growing season variability of net  
2830 ecosystem CO<sub>2</sub> exchange and evapotranspiration of a sphagnum mire in the broad-leaved  
2831 forest zone of European Russia. *Environ Res Lett* 8(3):035051. doi:10.1088/1748–  
2832 9326/8/3/035051.

2833 Oltchev A, Cermak J, Nadezhina N, Tatarinov F, Tishenko A, Ibrom A, Gravenhorst G  
2834 (2002a) Transpiration of a mixed forest stand: field measurements and simulation using  
2835 SVAT models. *Boreal Env Res* 7:389–397. <http://www.borenv.net/BER/pdfs/ber7/ber7-389.pdf>.

2837 Oltchev A, Cermak J, Gurtz J, Tishenko A, Kiely G, Nadezhina N, Zappa M, Lebedeva N,  
2838 Vitvar T, Albertson JD, Tatarinov F, Tishenko D, Nadezhdin V, Kozlov B, Ibrom A,  
2839 Vygodskaya N, Gravenhorst G. (2002b) The response of the water fluxes of the boreal  
2840 forest region at the Volga's source area to climatic and land-use changes. *Physics and  
2841 Chemistry of the Earth* 27(9–10):675–690. doi: 10.1016/S1474–7065(02)00052–9.

2842 Onuchin A, Korets M, Shvidenko A, Burenina T, Musokhranova A (2014) Modeling air  
2843 temperature changes in Northern Asia. *Global and Planetary Change* 122:14–22. doi:  
2844 10.1016/j.gloplacha.2014.07.011.

2845 Osadchiev A (2015) A method for quantifying freshwater discharge rates from satellite  
2846 observations and Lagrangian numerical modeling of river plumes. *Environ. Res Lett*,  
2847 10(8):085009.

2848 Oulehle F, McDowell WH, Aitkenhead-Peterson JA, Krám P, Hruška J, Navrátil T, Buzek F,  
2849 Fottová D (2008) Long-term trends in stream nitrate concentrations and losses across  
2850 watersheds undergoing recovery from acidification in the Czech Republic. *Ecosystems*  
2851 11(3):410–425. doi: 10/1007/s10021–008–9130–7.

2852 Oulehle F, Cosby BJ, Wright RF, Hruška J, Kopáček J, Krám P, Evans CD, Moldan F (2012)  
2853 Modelling soil nitrogen: The MAGIC model with nitrogen retention linked to carbon  
2854 turnover using decomposer dynamics. *Environmental Pollution* 165:158–166. doi:  
2855 10.1016/j.envpol.2012.02.021

2856 Oulehle F, Evans CD, Hofmeister J, Krejci R, Tahovska K, Persson T, Cudlin P, Hruska J  
2857 (2011) Major changes in forest carbon and nitrogen cycling caused by declining sulphur  
2858 deposition. *Glob Chang Biol* 17(10):3115–3129. doi: 10.1111/j.1365–2486.2011.02468.x.

2859 Overland JE, Hanna E, Hanssen-Bauer I, Kim B-M, Kim S-J, Walsh J, Wang M, Bhatt U  
2860 (2014) Air Temperature, in Arctic Report Card: Update for 2014.  
2861 [http://www.arctic.noaa.gov/report14/air\\_temperature.html](http://www.arctic.noaa.gov/report14/air_temperature.html).

2862 Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA, Phillips OL, Shvidenko  
2863 A, Lewis SL, Canadell JG, Ciais P, Jackson RB, Pacala SW, McGuire AD, Piao  
2864 S, Rautiainen A, Sitch S, Hayes D (2011) A large and persistent carbon sink in the world's  
2865 forests. *Science* 333:988–993. doi: 10.1126/science.1201609.

2866 Parfenova EI, Tchebakova NM, Vlasenko VI (2013) Possible change of ecosystems, species  
2867 ranges, and biodiversity in the Altai-Sayan ecoregion in a changing climate by 2050.  
2868 Chapter 6.2:267–288. In: Mikhailov NN (ed) Climate change and biodiversity in the  
2869 Russian portion of the Altai-Sayan ecoregion. UN Program on Development “Network  
2870 extension of exclusive protected natural territories in the Altai-Sayan ecoregion”.  
2871 Krasnoyarsk (in Russian).

2872 Parham LM, Prokushkin AS, Pokrovsky OS, Titov SV, Grekova E, Shirokova LS, McDowell  
2873 WH (2014) Permafrost and fire as regulators of stream chemistry in basins of the Central  
2874 Siberian Plateau. *Biogeochemistry* 116(1):55–68. doi: 10.1007/s10533-013-9922-5.

2875 Park T, Ganguly S, Tømmervik H, Euskirchen ES, Høgda K-A, Karlsen SR, Brovkin V,  
2876 Nemani RR, Myneni RB (2016) Changes in growing season duration and productivity of  
2877 northern vegetation inferred from long-term remote sensing data. *Environ Res Lett*  
2878 11:084001. doi:10.1088/1748-9326/11/8/084001.

2879 Park YH, Sokolik I (2016), Toward Developing a Climatology of Fire Emissions in Central  
2880 Asia, *Air, Soil and Water Research*, 9:87–96. doi:10.4137/ASWR.S39940.

2881 Pelyasov A (2011) European regional science: the strength of gaps in our knowledge (review  
2882 of the ERSA 2009 Lodz Congress papers). *ERSA conference papers*, European Regional  
2883 Science Association.

2884 Peng Y, Gitelson AA, Sakamoto T (2013) Remote estimation of gross primary productivity in  
2885 crops using MODIS 250 m data. *Remote Sensing of Environment* 128:186–196. doi:  
2886 10.1016/j.rse.2012.10.005.

2887 Peterson BJ, Holmes RM, McClelland JW, Vörösmarty CJ, Lammers RB, Shiklomanov AI,  
2888 Shiklomanov IA, Rahmstorf S (2002) Increasing river discharge to the Arctic Ocean.  
2889 *Science* 298(5601):2171–2173. doi: 10.1126/science.1077445.

2890 Peterson LK, Bergen KM, Brown DG, Vashchuk L, Blam Y (2009) Forested land-cover  
2891 patterns and trends over changing forest management eras in the Siberian Baikal region.  
2892 *Forest Ecology and Management* 257:911-922. doi: 10.1016/j.foreco.2008.10.037

2893 Pieczonka T, Bolch T (2015) Region-wide glacier mass budgets and area changes for the  
2894 Central Tien Shan between ~1975 and 1999 using Hexagon KH-9 imagery. *Global and*  
2895 *Planetary Change* 128:1–13. doi: 10.1016/j.gloplacha.2014.11.014.

2896 Pokrovsky OS, Viers J, Dupré B, Chabaux F, Gaillardet J, Audry S, Prokushkin AS,  
2897 Shirokova LS, Kirpotin SN, Lapitsky SA, Shevchenko VP (2012) Biogeochemistry of  
2898 carbon, major and trace elements in watersheds of northern Eurasia drained to the Arctic  
2899 Ocean: The change of fluxes, sources and mechanisms under the climate warming  
2900 prospective. *Comptes Rendus Geoscience* 344(11–12):663–677. doi:  
2901 10.1016/j.crte.2012.08.003.

2902 Polishchuk VY, Polishchuk YM (2013) Geoimitational modeling of the thermokarst lakes  
2903 pattern in the permafrost zones. *Yugra State University Publ. Khanty-Mansijsk* (in  
2904 Russian). ISBN 978–5–9611–0079–2.

2905 Polishchuk VY, Polishchuk YM (2014) Modeling of thermokarst lake dynamics in West  
2906 Siberian permafrost, in "Permafrost: Distribution, Composition and Impacts on  
2907 Infrastructure and Ecosystems", Pokrovsky, O., Ed., New York: Nova Sci. Publ., 2014,  
2908 chap. 6, pp. 205–234. doi 10.978 94 007 4569 8.

2909 Polishchuk YM, Bryksina NA, Polishchuk VY (2015) Remote Analysis of Changes in the  
2910 Number and Distribution of Small Thermokarst Lakes by Sizes in Cryolithozone of  
2911 Western Siberia, 2015. *Studying of the Earth from Space*, 2015(3):34–42. doi:  
2912 10.7868/S0205961415030100.

2913 Porfiriev BN (2001) Instant and creeping environmental crises in Russia. In: Rosenthal U,  
2914 Boin AR Comfort LK (eds) *Managing Crises: Threats, Dilemmas and Opportunities*.  
2915 Charles Thomas Publisher Ltd, Springfield, Illinois.

2916 Porfiriev BN (2012) Economic issues of disaster and disaster risk reduction policies:  
2917 international versus Russian perspectives. *Intern J Disaster Risk Reduction* 1:55–61. doi:  
2918 10.1016/j.ijdrr.2012.05.005.

2919 Porfiriev BN (2013) Assessment and forecast of the technological risks of long-term  
2920 economic growth in Russia. *Studies in Russian Economic Development* 24(4):316–332.

2921 Porfiriev BN (2014) Evaluation of human losses from disasters: The case of the 2010 heat  
2922 waves and forest fires in Russia. *Intern J Disaster Risk Reduction* 7:91–99. doi:  
2923 10.1016/j.ijdrr.2013.12.007.

2924 Porfiriev BN (2016) The economics of natural disasters. *Herald Russ Acad Sci* 86(1):1–11.

2925 Potapov PV, Turubanova SA, Tyukavina A, Krylov AM, McCarty JL, Radeloff VC, Hansen,  
2926 MC (2015) Eastern Europe's forest cover dynamics from 1985 to 2012 quantified from the  
2927 full Landsat archive. *Remote Sensing of Environment* 159:28–43. doi:  
2928 10.1016/j.rse.2014.11.027.

2929 Potapov P, Turubanova S, Zhuravleva I, Hansen M, Yaroshenko A, Manisha A (2012) Forest  
2930 cover change within the Russian European North after the breakdown of Soviet Union  
2931 (1990–2005). *Int J Forestry Research* 2012:729614. doi: 10.1155/2012/729614.

2932 Potapov P, Yaroshenko A, Turubanova S, Dubinin M, Laestadius L, Thies C, Aksenov D,  
2933 Egorov A, Yesipova Y, Glushkov I, Karpachevskiy M, Kostikova A, Manisha A,  
2934 Tsybikova E, Zhuravleva I (2008) Mapping the world's intact forest landscapes by remote  
2935 sensing. *Ecology and Society* 13(2):51. <http://www.ecologyandsociety.org/vol13/iss2/art51>.

2937 Prinn RG (2013) Development and application of earth system models. *Proc Nat Acad Sci*  
2938 USA 110(Suppl 1):3673–3680. doi: 10.1073/pnas.1107470109.

2939 Prinn RG, Jacoby H, Sokolov A, Wang C, Xiao X, Yang Z, Eckhaus R, Stone P, Ellerman D,  
2940 Melillo J, Fitzmaurice J, Kicklighter D, Holian G, Liu Y (1999) Integrated global system  
2941 model for climate policy assessment: Feedbacks and sensitivity studies. *Climatic Change*  
2942 41(3–4):469–546. doi: 10.1023/A:1005326126726.

2943 Prishchepov AV, Müller D, Baumann M, Kuemmerle T, Alcantara C, Radeloff VS (2017)  
2944 Underlying drivers and spatial determinants of post-Soviet agricultural land abandonment  
2945 in Temperate Eastern Europe. In *Land-Cover and Land-Use Changes in Eastern Europe*  
2946 after the Collapse of the Soviet Union in 1991 1–27 Switzerland: Springer International  
2947 Publishing. doi: 10.1007/978-3-319-42638-9\_5.

2948 Prishchepov AV, Müller D, Dubinin M, Baumann M, Radeloff VC (2013) Determinants of  
2949 agricultural land abandonment in post-Soviet European Russia. *Land Use Policy*  
2950 30(1):873–884. doi: 10.1016/j.landusepol.2012.06.011.

2951 Prishchepov AV, Radeloff, VC, Baumann M, Kuemmerle T, Müller D (2012) Effects of  
2952 institutional changes on land use: agricultural land abandonment during the transition from  
2953 state-command to market-driven economies in post-Soviet Eastern Europe. *Environ Res*  
2954 Lett 7(2):024021. doi: 10.1088/1748–9326/7/2/024021.

2955 Qi J, Bobushev TS, Kulmatov R, Groisman P, Gutman G (2012b) Addressing global change  
2956 challenges for Central Asian socio-ecosystems. *Frontiers of Earth Sci* 6(2):115–121. doi:  
2957 10.1007/s11707–012–0320–4.

2958 Qi J, Chen J, Wan S, Ai L (2012a) Understanding the coupled natural and human systems in  
2959 the Dryland East Asia. *Environ Res Lett* 7(1):015202. doi: 10.1088/1748–  
2960 9326/7/1/015202.

2961 Rahmstorf S (2002) Ocean circulation and climate during the past 120,000 years. *Nature*  
2962 419(6903):207–214. doi: 10.1038/nature01090.

2963 Rawlins MA, McDonald KC, Frolking S, Lammers RB, Fahnestock M, Kimball JS, C.J.  
2964 Vörösmarty CJ (2005) Remote sensing of snow thaw at the pan-Arctic scale using the  
2965 SeaWinds scatterometer. *J Hydrology* 312(1–4):294–311. doi:  
2966 10.1016/j.jhydrol.2004.12.018.

2967 Rawlins MA, McGuire AD, Kimball JS, Dass P, Lawrence D, Burke E, Chen X, Delire C,  
2968 Koven C, A. MacDougall A, Peng S, Rinke A, Saito K, W. Zhang W Alkama R, Bohn TJ,  
2969 Ciais P, Decharme B, Gouttevin I, Hajima T, Ji D, Krinner G, Lettenmaier DP, Miller P,  
2970 Moore JC, Smith B, Sueyoshi T (2015) Assessment of model estimates of land-atmosphere  
2971 CO<sub>2</sub> exchange across Northern Eurasia. *Biogeosciences* 12:4385–4405. doi: 10.5194/bg-  
2972 4385–2015.

2973 Rawlins MA, Steele M, Serreze MC, Vörösmarty CJ, Ermold W, Lammers RB, McDonald  
2974 KC, Pavelsky TM, Shiklomanov A, Zhang J (2009) Tracing freshwater anomalies through  
2975 the air-land-ocean system: A case study from the Mackenzie River basin and the Beaufort  
2976 Gyre. *Atmos-Ocean* 47(1):79–97. doi: 10.3137/OC301.2009.

2977 Rawlins MA, Steele M, Holland M, Adam J, Cherry J, Francis J, Groisman P, Hinzman L,  
2978 Huntington T, Kane D, Kimball J, Kwok R, Lammers R, Lee C, Lettenmaier D, McDonald  
2979 K, Podest E, Pundsack J, Rudels B, Serreze M, Shiklomanov A, Skagseth Ø, Troy  
2980 TJ, Vörösmarty CJ, Wensnahan M, Wood, EF Woodgate R, Yang D, Zhang K, T (2010)  
2981 Analysis of the Arctic System for Freshwater Cycle Intensification: Observations and  
2982 Expectations. *J. Climate* 23:5715–5737. doi: 10.1175/2010JCLI3421.1.

2983 Reynolds MK, Walker DA, Ambrosius KJ, Brown J, Everett KR, Kanevskiy M, Kofinas GP,  
2984 Romanovsky VE, Shur Y, Webber PJ (2014) Cumulative geoecological effects of 62 years

2985 of infrastructure and climate change in ice-rich permafrost landscapes, Prudhoe Bay  
2986 Oilfield, Alaska. *Global Change Biology* 20(4):1211–1224. doi: 10.1111/gcb.12500.

2987 Reid PC., Hari RE, Beaugrand G, Livingstone DM, Marty C, Straile D, Barichivich J,  
2988 Goberville E, Adrian R, Aono Y, Brown R, Foster J, , Groisman P, Helaouet P, Hsu HH,  
2989 Kirby R, ,Knight J, Kraberg A, Li J, Lo TT, Myneni RB, North RP, Pounds JA, Sparks  
2990 T, Stubi R, Tian Y, Wiltshire KH, Xiao D, Zhu Z (2016) Global impacts of the 1980s  
2991 regime shift. *Global Change Biology*, 22: 682–703. doi: 10.1111/gcb.13106.

2992 Reilly J, Melillo J, Cai Y, Kicklighter D, Gurgel A, Paltsev S, Cronin T, Sokolov A, Schlosser  
2993 A (2012) Using land to mitigate climate change: hitting the target, recognizing the  
2994 tradeoffs. *Environ Sci Technol* 46(11):5672–5679. doi: 10.1021/es2034729.

2995 Renner AHH, Gerland S, Haas C, Spreen G, Beckers JF, Hansen E, Nicolaus M, Goodwin H  
2996 (2014) Evidence of Arctic sea ice thinning from direct observations. *Geophys Res Lett*  
2997 41(14): 5029 –5036. doi: 10.1002/2014GL060369.

2998 Riahi K, Grübler A, Nakicenovic N (2007) Scenarios of long-term socio-economic and  
2999 environmental development under climate stabilization. *Technological Forecasting and*  
3000 *Social Change* 74(7):887–935.

3001 Richter-Menge J, Walsh JE, Brigham LW, Francis AA, Holland M, Nghiem SV, Raye R,  
3002 Woodgate R (2012) Seasonal-to-Decadal Predictions of Arctic Sea Ice: Challenges and  
3003 strategies. Committee on the Future of Arctic Sea Ice Research in Support of Seasonal to  
3004 Decadal Prediction, Polar Res. Board, Div. Earth and Life Studies, Nat. Res. Council,  
3005 ISBN-13: 978-0-309-26526-3, National Academy of Sciences.

3006 Rimkus E, Stonevicius E, Korneev VR, Kažys J, Valiuškevicius G, Pakhomau A (2013)  
3007 Dynamics of meteorological and hydrological droughts in the Neman river basin. *Environ*  
3008 *Res Lett* 8(4):045014. doi: 10.1088/1748-9326/8/4/045014.

3009 Robinson DT, Sun S, Hutchins M, Riolo RL, Brown DG, Parker DC, Filatova T, Currie WS,  
310 Kiger S (2013) Effects of land markets and land management on ecosystem function: A  
311 framework for modelling exurban land change. *Environmental Modelling and Software*  
312 45:129–140. doi: 10.1016/j.envsoft.2012.06.016.

313 Rogers BM, Soja AJ, Goulden ML, Randerson JT (2015) Influence of tree species on  
314 continental differences in boreal fires and climate feedbacks. *Nature Geoscience* 8:228–  
315 234. doi: 10.1038/ngeo2352.

316 Romanenkov V, Rukhovitch D, Koroleva P McCarty JL (2014) Estimating Black Carbon  
317 Emissions from Agricultural Burning. In: Mueller L, Lischeid G, Saparov A (eds) *Novel*  
318 *Measurement and Assessment Tools for Monitoring and Management of Land and Water*  
319 *Resources in Agricultural Landscapes of Central Asia*. Springer, New York.

320 Romanovsky VE, Drozdov DS, Oberman NG, Malkova GV, Kholodov AL, Marchenko SS,  
321 Moskalenko NG, Sergeev DO, Ukraintseva NG, Abramov AA, Gilichinsky DA, Vasiliev  
322 AA (2010a) Thermal State of Permafrost in Russia. *Permafrost and Periglacial Process*  
323 21:136–155. doi: 10.1002/ppp.683.

324 Romanovsky VE, Smith SL, Christiansen HH (2010b) Permafrost thermal state in the polar  
325 Northern Hemisphere during the international polar year 2007–2009: a synthesis.  
326 *Permafrost and Periglacial Process* 21(2):106–116. doi:10.1002/ppp.689.

327 Romanovsky VE, Smith SL, Shiklomanov NI, Marchenko SS (2017) Terrestrial Permafrost.  
328 *Bull Amer Meteorol Soc* 98(8) 147–149.

329 Rosenzweig C, Elliott J, Deryng D, Ruane AC, Müller C, Arneth A, Boote KJ, Folberth C,  
330 Glotter M, Khabarov N, Neumann K, Piontek F, Pugh TAM, Schmid E, Stehfest E, Yang  
331 H, Jones J.W (2014) Assessing agricultural risks of climate change in the 21st century in a  
332 global gridded crop model intercomparison. *Proc Nat Acad Sci USA* 111(9):3268–3273.  
333 doi: 10.1073/pnas.1222463110.

3034 Rossini M, Migliavacca M, Galvagno M, Meroni M, Cogliati S, Cremonese E, Fava F,  
3035 Gitelson A, Julitta T, Morra di Cella U, Siniscalco C, Colombo R (2014) Remote  
3036 estimation of grassland gross primary production during extreme meteorological seasons.  
3037 Intern J Applied Earth Observation and Geoinformation **29**:1–10. doi:  
3038 10.1016/j.jag.2013.12.008.

3039 Rosstat (2016) Central statistical database. Rosstat. Federal service of state statistics of  
3040 Russian Federation. Retrieved from <http://www.gks.ru/dbscripts/Cbsd/DBInet.cgi>.

3041 Rotmans J, de Boois H, Swart RJ (1990) An integrated model for the assessment of the  
3042 greenhouse effect: the Dutch approach. Climatic Change 16(3):331–356. doi:  
3043 10.1007/BF00144508.

3044 Ruppel CD, Kessler JD (2017) The interaction of climate change and methane hydrates,  
3045 Reviews of Geophysics 55:126–168. doi: 10.1002/2016RG000534.

3046 Sabrekov AF, Glagolev MV, Alekseychik PK, Smolentsev BA, Terentieva IE, Krivenok LA,  
3047 Maksyutov SS (2016) A process-based model of methane consumption by upland soils.  
3048 *Environ Res Lett* 11(7):075001.

3049 Sabrekov AF, Runkle BRK, Glagolev MV, Kleptsova IE, Maksyutov SS (2014) Seasonal  
3050 variability as a source of uncertainty in the West Siberian regional CH<sub>4</sub> flux upscaling.  
3051 *Environ Res Lett* 9(4):045008.

3052 Saeki T, Maksyutov S, Sasakawa M, Machida T, Arshinov M, Tans P, Conway TJ, Saito M,  
3053 Valsala V, Oda T, Andres RJ, Belikov D (2013) Carbon flux estimation for Siberia by  
3054 inverse modeling constrained by aircraft and tower CO<sub>2</sub> measurements, *J Geophys Res*  
3055 118(2):1100–1122. doi: 10.1002/jgrd.50127.

3056 Schaphoff S, Lucht W, Gerten D, Sitch S, Cramer W, Prentice IC (2006) Terrestrial biosphere  
3057 carbon storage under alternative climate projections. *Climatic Change* 74(1–3):97–122.  
3058 doi: 10.1007/s10584-005-9002-5.

3059 Schaphoff S, Reyer CPO, Schepaschenko D, Gerten D, Shvidenko A (2015) Tamm Review:  
3060 Observed and projected climate change impacts on Russian forests and its carbon balance.  
3061 Forest Ecology and Management 361:432–444. doi: 10.1016/j.foreco.2015.11.043.

3062 Schepaschenko DG, Mukhortova LV, Shvidenko AZ, Vetrova EF (2013) The pool of organic  
3063 carbon in the soils of Russia. Eurasian Soil Science 46(2): 107–116. doi:  
3064 10.1134/S1064229313020129.

3065 Schierhorn F, Faramarzi M, Prishchepov AV, Koch FJ, Müller D (2014a) Quantifying yield  
3066 gaps in wheat production in Russia. Environ Res Lett 9(8):084017. doi: 10.1088/1748–  
3067 9326/9/8/084017.

3068 Schierhorn F, Müller D, Beringer, T, Prishchepov AV., Kuemmerle T, Balmann A (2013)  
3069 Post-Soviet cropland abandonment and carbon sequestration in European Russia, Ukraine,  
3070 and Belarus. Global Biogeochemical Cycles 27(4):1175–1185. doi:  
3071 10.1002/2013GB004654.

3072 Schierhorn F, Müller D, Prishchepov AV, Faramarzi M, Balmann A (2014b) The potential of  
3073 Russia to increase its wheat production through cropland expansion and intensification.  
3074 Global Food Security 3(3–4):133–141. doi: 10.1016/j.gfs.2014.10.007.

3075 Schöpp W, Posch M, Mylona S, Johansson M (2003) Long-term development of acid  
3076 deposition (1880–2030) in sensitive freshwater regions in Europe. Hydrol Earth Syst Sci  
3077 7(4):436–446. doi: 10.5194/hess-7-436-2003.

3078 Schubert SD, Wang H, Koster RD, Suarez MJ, Groisman PY (2014) Northern Eurasian heat  
3079 waves and droughts. J Climate 27(9):3169–3207. doi: 10.1175/JCLI-D-13-00360.1.

3080 Schulze E-D, Wirth C, Mollicone D, von Lüpke N, Ziegler W, Achard F, Mund M,  
3081 Prokushkin A, Scherbina S (2012) Factors promoting larch dominance in central Siberia:  
3082 Fire versus growth performance and implications for carbon dynamics at the boundary of

3083 evergreen and deciduous conifers. *Biogeosciences* 9:1405–1421. doi: 10.5194/bg-9-1405–  
3084 2012.

3085 Sedykh VN (2014) Dynamics of plain Siberian pine forests of Siberia. Nauka, Novosibirsk  
3086 (In Russian).

3087 Semenov VA (2012) Meteorology: Arctic warming favours extremes. *Nature Climate Change*  
3088 2:315–316. doi: 10.1038/nclimate1502.

3089 Serreze MC, Barrett AP, Slater AG, Woodgate RA, Aagaard K, Lammers RB, Steele M,  
3090 Moritz R, Meredith M, Lee CM (2006) The large-scale freshwater cycle of the Arctic. *J  
3091 Geophys Res* 111(C11):C11010. doi: 10.1029/2005JC003424.

3092 Severskiy I, Vilesov E, Armstrong R, Kokarev A, Kogutenko L, Usmanova Z (2016) Changes  
3093 in glaciation of the Balkhash-Alakol Basin over the past decades. *Ann Glaciol* 57(71):382–  
3094 394. doi: 10.3189/2016AoG71A575.

3095 Shahgedanova M, Afzal M, Usmanova Z, Kapitsa V, Mayr E, Hagg W, Severskiy I,  
3096 Zhumabayev D (2016) Impacts of climate change on river discharge in the northern Tien  
3097 Shan: Results from long-term observations and modelling. pp 248–258 in: Medeu A (ed)  
3098 Water Resources in Central Asia and Their Use. Almaty, Kazakhstan.

3099 Shahgedanova M, Nosenko G, Bushueva I, Ivanov M (2012) Changes in Area and Geodetic  
3100 Mass Balance of Small Glaciers, Polar Urals, Russia, 1950–2008. *J Glaciology*  
3101 58(211):953–964. doi: 10.3189/2012JoG11J233.

3102 Shahgedanova M, Nosenko G, Khromova T, Muravyev A (2010) Glacier shrinkage and  
3103 climatic change in the Russian Altai from the mid-20<sup>th</sup> Century: An assessment using  
3104 remote sensing and PRECIS regional climate model. *J Geophys Res - Atmos*  
3105 115(D16):D16107. doi: 10.1029/2009JD012976.

3106 Shahgedanova M, Nosenko G, Kutuzov S, Rototaeva O, Khromova T (2014) Deglaciation of  
3107 the Caucasus Mountains, Russia/Georgia in the 21st century observed with ASTER

3108 satellite imagery and aerial photography. *The Cryosphere* 8:2367–2379. doi: 10.5194/tc-8–  
3109 2367–2014.

3110 Shahgedanova M, Popovnin V, Aleynikov A, Stokes CR (2011) Geodetic mass balance of the  
3111 Azarova Glacier, Kodar Mountains, eastern Siberia and its links to observed and projected  
3112 climatic changes. *Annals of Glaciology* 52(58):129–137.

3113 Shakhova N, Semiletov I, Leifer I, Sergienko V, Salyuk A, Kosmach D, Chernykh D, Stubbs  
3114 C, Nicolsky D, Tumskoy V, Gustafsson Ö (2013) Ebullition and storm-induced methane  
3115 release from the East Siberian Arctic Shelf. *Nature Geoscience* 7:64–70. doi:  
3116 10.1038/NGEO2007.

3117 Shakhova N, Semiletov I, Sergienko V, Lobkovsky L, Yusupov V, Salyuk A, Salomatin A,  
3118 Chernykh D, Kosmach D, Panteleev G, Nicolsky D, Samarkin V, Joye S, Charkin A,  
3119 Dudarev O, Meluzov A, Gustafsson Ö (2015) The East Siberian Arctic Shelf: towards  
3120 further assessment of permafrost-related methane fluxes and role of sea ice. *Phil Trans Roy  
3121 Soc A* 373:20140451. doi: 10.1098/rsta.2014.0451.

3122 Shiklomanov AI, Lammers RB (2011) River Discharge in Arctic. State of the Climate in  
3123 2010. *Bull Amer Meteor Soc* 92(6):S153–S154. doi: 10.1175/1520–0477–92.6.S1.

3124 Shiklomanov AI, Lammers RB (2013) Changing Discharge Patterns of High-Latitude Rivers,  
3125 In: Pielke RA (ed) *Climate Vulnerability: Understanding and Addressing Threats to*  
3126 *Essential Resources. Volume 5: Vulnerability of Water Resources to Climate*, Academic  
3127 Press, Oxford, UK. ISBN 9780123847041. doi: 10.1016/B978–0–12–384703–4.00526–8.

3128 Shiklomanov AI, Lammers RB (2014) River ice responses to a warming Arctic—recent  
3129 evidence from Russian rivers. *Environ Res Lett* 9(3):035008. doi: 10.1088/1748–  
3130 9326/9/3/035008.

3131 Shiklomanov AI, Lammers RB (2009) Record Russian river discharge in 2007 and the limits  
3132 of analysis. *Environ Res Lett* 4(4):045015. doi: 10.1088/1748–9326/4/4/045015.

3133 Shiklomanov AI, Lammers RB, Lettenmaier DP, Polischuk YM, Savichev OG, Smith LS,  
3134 Chernokulsky AV (2013) Hydrological Changes: Historical Analysis, Contemporary  
3135 Status, and Future Projections. In: Groisman PY, Gutman G (eds) *Regional Environmental*  
3136 *Changes in Siberia and their Global Consequences*. Springer, Dordrecht. doi:  
3137 10.1007/978-94-007-4569-8\_4.

3138 Shiklomanov AI, Lammers RB, Rawlins MA, Smith LS, Pavelsky TM (2007) Temporal and  
3139 spatial variations in maximum river discharge from a new Russian data set. *J Geophys Res*  
3140 - *Biogeosciences* 112(G4):G04S53. doi: 10.1029/2006JG000352.

3141 Shiklomanov NI, Streletsckiy DA (2013) Effect of Climate Change on Siberian Infrastructure.  
3142 In: Groisman PY, Gutman G (eds) (2013) *Environmental Changes in Siberia: Regional*  
3143 *Changes and their Global Consequences*. Springer, Dordrecht.

3144 Shiklomanov NI, Streletsckiy DA, Swales TB, Kokorev VA (2017) Climate Change and  
3145 Stability of Urban Infrastructure in Russian Permafrost Regions: Prognostic Assessment  
3146 based on GCM Climate Projections. *Geograph Rev* 107(1):125–142.  
3147 doi:10.1111/gere.12214.

3148 Shkolnik IM, Efimov SV (2013) Cyclonic activity in high latitudes as simulated by a regional  
3149 atmospheric climate model: added value and uncertainties. *Environ Res Lett* 8(4):045007.  
3150 doi: 10.1088/1748-9326/8/4/045007.

3151 Shkolnik IM, Meleshko VP, Efimov SV, Stafeeva EN (2012a) Changes in climate extremes  
3152 on the territory of Siberia by the middle of the 21st century: ensemble forecast based on  
3153 the MGO regional climate model. *Russ Meteorol Hydrol* 37(2):71–84.

3154 Shkolnik IM, Nadyozhina ED, Pavlova TV, Khlebnikova EI, Semioshina AA, Molkentin EK,  
3155 Stafeeva EN (2012b) Simulation of the regional features of the seasonal thawing layer in  
3156 the Siberian permafrost zone. *Earth Cryo* 16:52–59 (in Russian).  
3157 <http://www.izdatgeo.ru/pdf/krio/2012-2/52.pdf>

3158 Shkolnik I., Pavlova T., Efimov S. Zhuravlev S (2017) Future changes in peak river flows  
3159 across northern Eurasia as inferred from an ensemble of regional climate projections under  
3160 the IPCC RCP8.5 scenario. *Clim Dyn* <https://doi.org/10.1007/s00382-017-3600-6>.

3161 Shuman JK, Shugart HH (2009) Evaluating the sensitivity of Eurasian forest biomass to  
3162 climate change using a dynamic vegetation model. *Environ Res Lett* 4(4):045024. doi:  
3163 10.1088/1748-9326/4/4/045024.

3164 Shuman JK, Shugart HH (2012) Resilience and stability associated with the conversion of  
3165 boreal forest. In: Fatoyinbo TE (ed) *Remote Sensing of Biomass: Principles and*  
3166 *Application*. Book 1. Intech Open Access Publishing. ISBN: 978-953-51-0313-4

3167 Shuman JK, Shugart HH Krankina ON (2013a) Assessment of carbon stores in tree biomass  
3168 for two management scenarios in Russia. *Environ Res Lett* 8(4):045019. doi:  
3169 10.1088/1748-9326/8/4/045019.

3170 Shuman JK, Shugart HH Krankina ON (2013b) Testing individual-based models of forest  
3171 dynamics: Issues and an example from the boreal forests of Russia. *Ecological Modelling*  
3172 293:102–110. doi: 10.1016/j.ecolmodel.2013.10.028.

3173 Shuman JK, Tchebakova NM, Parfenova EI, Soja AJ, Shugart HH, Ershov D, Holcomb K  
3174 (2015) Forest forecasting with vegetation models across Russia. *Can J For Res* 45(2):175–  
3175 184. doi: 10.1139/cjfr-2014-0138.

3176 Shur YL, Goering DJ (2009) Climate change and foundations of buildings in permafrost  
3177 regions. In: Margesin R, (ed) *Permafrost Soils*, Springer, Berlin.

3178 Shvetsov EG, Kukavskaya EA, Buryak LV (2016) Satellite monitoring of the state of forest  
3179 vegetation after fire impacts in the Zabaykal region. *Contemporary problems of ecology* 9  
3180 (6):763–771.

3181 Shvidenko AZ, Nilsson S (1994) What do we know about the Siberian forests? *Ambio*  
3182 23(7):396–404.

3183 Shvidenko AZ, Schepaschenko DG (2013) Climate change and wildfires in Russia.  
3184 Contemporary Problems of Ecology 6(7):683–692. doi: 10.1134/S199542551307010X.

3185 Shvidenko AZ, Schepaschenko DG (2014) Carbon budget of forests in Russia. Siberian  
3186 Journal of Forest Science 2014(1):69–92 (in Russian).

3187 Shvidenko AZ, Gustafson E, McGuire D, Kharuk VI, Schepaschenko D, Shugart HH,  
3188 Tchebakova NM, Vygodskaya NN, Onuchin AA, Hayes DJ, McCallum I, Maksyutov S,  
3189 Mukhortova LV, Soja AJ, Belelli-Marchesini L, Kurbatova JA, Oltchev AV, Parfenova EI,  
3190 Shuman JK (2013): Terrestrial ecosystems and their change. In: Groisman PY, Gutman G  
3191 (eds) Regional Environment Change in Siberia and their Global Consequences. Springer,  
3192 Dordrecht.

3193 Shvidenko AZ, Schepaschenko DG, Vaganov EA., Sukhinin AI, Maksyutov SS, McCallum I,  
3194 Lakyda PI (2011) Impacts of wildfire in Russia between 1998–2010 on ecosystems and the  
3195 global carbon budget. Doklady Earth Sciences 441(2):1678–1682.

3196 Siljamo P, Sofiev M, Filatova E, Grewling L, Jäger S, Khoreva E, Linkosalo T, Ortega  
3197 Jimenez S, Ranta H, Rantio-Lehtimäki A, Svetlov A, Veriankaite L, Yakovleva E,  
3198 Kukkonen J (2013) A numerical model of birch pollen emission and dispersion in the  
3199 atmosphere. Model evaluation and sensitivity analysis. Int J Biometeorol 57(1):125–136.  
3200 doi: 10.1007/s00484–012–0539–5.

3201 Smaliychuk A, Müller D, Prishchepov AV, Levers C, Kruhlov I, Kuemmerle T (2016)  
3202 Recultivation of abandoned agricultural lands in Ukraine: Patterns and drivers. Global  
3203 Environmental Change 38:70–81. doi: 10.1016/j.gloenvcha.2016.02.009

3204 Smith LC, Pavelsky TM, MacDonald GM, Shiklomanov AI, Lammers RB (2007) Rising  
3205 minimum daily flows in northern Eurasian rivers: a growing influence of groundwater in  
3206 the high-latitude hydrologic cycle. J Geophys Res - Biogeosciences 112(G4):G04S47. doi:  
3207 10.1029/2006JG000327.

3208 Smith LC, Sheng Y, MacDonald GM, Hinzman LD (2005) Disappearing Arctic Lakes.  
3209 Science 308(5727):1429. doi: 10.1126/science.1108142.

3210 Sofiev M, Siljamo P, Ranta H, Linkosalo T, Jaeger S, Rasmussen A, Rantio-Lehtimaki A,  
3211 Severova E, Kukkonen J (2013) A numerical model of birch pollen emission and  
3212 dispersion in the atmosphere. Description of the emission module. Int J Biometeorol  
3213 57(1):45–58. doi: 10.1007/s00484-012-0532-z.

3214 Soja AJ, Cofer WR, Shugart HH, Sukhinin AI, Stackhouse Jr PW, McRae DJ, Conard SG  
3215 (2004) Estimating fire emissions and disparities in boreal Siberia (1998 – 2002). J  
3216 Geophys Res 109(D14):D14S06. doi: 10.1029/2004JD004570.

3217 Soja AJ, Tchebakova NM, French NHF, Flannigan MD, Shugart HH, Stocks BJ, Sukhinin AI,  
3218 Parfenova EI, Chapin 3<sup>rd</sup> FS, Stackhouse Jr PW (2007) Climate-induced boreal forest  
3219 change: Predictions versus current observations. *Glob and Planet Change* 56 (3–4):274–  
3220 296. doi: 10.1016/j.gloplacha.2006.07.028.

3221 Sokolik IN (2013) Dust. In: Encyclopedia of Atmospheric Sciences. Second Edition,  
3222 Academic Press, London.

3223 Sokolik IN, Darmenova K, Huang J, Kalashnikova O, Kurosaki Y, Xi X (2013) Examining  
3224 changes in land cover and land use, regional climate and dust in dryland East Asia and  
3225 their linkages within the Earth. In: Chen J, Wan S, Henebry G, Qi J, Gutman G, Ge S  
3226 Kappas M (eds) Dryland East Asia: Land Dynamics amid Social and Climate Change. De  
3227 Gruyter Publ. House Amsterdam, Higher Education Press, Beijing. doi:  
3228 10.1515/9783110287912.183.

3229 Sokolov AP, Schlosser CA, Dutkiewicz S, Paltsev S, Kicklighter DW, Jacoby HD, Prinn RG,  
3230 Forest CE, Reilly J, Wang C, Felzer B, Sarofim MC, Scott J, Stone PH, Melillo JM, Cohen  
3231 J (2005) The MIT Integrated Global System Model (IGSM) Version 2: Model Description

3232 and Baseline Evaluation. MIT Joint Program on the Science and Policy of Global Change.  
3233 Report 124. [http://globalchange.mit.edu/files/document/MITJPSPGC\\_Rpt124.pdf](http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt124.pdf).

3234 Sokolov AP, Stonw PH, Forest CE, Prinn R, Sarofim MC, Webster M, Paltsev S, Schlosser  
3235 CA, Kicklighter D, Dulkiewicz S, Reilly J, Wang C, Feltzer B, Melillo JM, Jakoby HD  
3236 (2009) Probabilistic forecast for twenty-first-century climate based on uncertainties in  
3237 emissions (without policy) and climate parameters. *J Climate* 22:5175–5204. doi:  
3238 10.1175/2009JCLI2863.1.

3239 Sokratov VS, Shmakin AB (2013) Numerical modeling of snow cover on Hooker Island  
3240 (Franz Josef Land archipelago. *Ice and Snow* 2013(3): 55–62 (in Russian with English  
3241 Summary).

3242 Sorg A, Bolch T, Stoffel M, Solomina O, Beniston M (2012) Climate change impacts on  
3243 glaciers and runoff in Tien Shan (Central Asia). *Nature Climate Change* 2:725–731. doi:  
3244 10.1038/nclimate1592.

3245 Speranskaya NA (2011) Changes in some elements of the water cycle in the easternmost part  
3246 of the Baltic Sea Drainage Basin between 1945 and 2010. *Oceanologia* 53(Suppl 1):279–  
3247 292. doi: 10.5697/oc.53-1-TI.279.

3248 Speranskaya NA (2016) Actual evaporation from natural green land over European Russia:  
3249 available observations and restored data. *Izvestiya RAS. Seria Geograficheskaya*  
3250 2016(2):49–60 (in Russian).

3251 Stammler F (2005) Reindeer Nomads Meet the Market: Culture, Property and Globalization  
3252 at the End of the Land. Litverlag, Halle Studies in the Anthropology of Eurasia, Muenster.

3253 Stephens BB, Gurney KR, Tans PP, Sweeney C, Peters W, Bruhwiler L, Ciais P, Ramonet M,  
3254 Bousquet P, Nakazawa T, Aoki S., Machida T, Inoue G, Vinnichenko N, Lloyd J, Jordan  
3255 A, Heimann M, Shibistova O, Langenfelds RL, Steele LP, Francey RJ, Denning AS (2007)

3256 Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric  
3257 CO<sub>2</sub>. *Science* 316(5832):1732–1735. doi: 10.1126/science.1137004.

3258 Stephenson SR, Smith LC, Agnew JA (2011) Divergent long-term trajectories of human  
3259 access to the Arctic. *Nature Climate Change*, 1(3):256–160. doi: 10.1038/nclimate1120.

3260 Stokes CR, Shahgedanova M, Evans IS, Popovnin VV (2013) Accelerated loss of alpine  
3261 glaciers in the Kodar Mountains, south-eastern Siberia. *Global and Planetary Change*  
3262 101:82–96.

3263 Strategic Assessment of Development of the Arctic (2014) ‘Changes in Arctic Maritime  
3264 Transport’ [factsheet]. - URL: [www.arcticinfo.eu](http://www.arcticinfo.eu).

3265 Streletskiy DA, Anisimov O, Vasiliev A (2015a) Permafrost degradation. In: Haeberli W,  
3266 Whiteman C, Shroder Jr JF (eds) *Snow and Ice Related Risks, Hazards and Disasters*.  
3267 Elsevier, Oxford, UK. doi: 10.1016/B978-0-12-394849-6.00010-X.

3268 Streletskiy DA, Shiklomanov NI, Nelson FE (2012) Permafrost, infrastructure and climate  
3269 change: A GIS-based landscape approach to geotechnical modeling. *Arctic Antarctic*  
3270 *Alpine Res* 44(3):368–380. doi: 10.1657/1938-4246-44.3.368.

3271 Streletskiy DA, Tananaev NI, Opel T, Shiklomanov NI, Nyland KE, Streletskaia ID, Tokarev  
3272 I. Shiklomanov AI (2015b) Permafrost hydrology in changing climatic conditions:  
3273 seasonal variability of stable isotope composition in rivers in discontinuous permafrost.  
3274 *Environ Res Lett* 10(9):095003. doi: 10.1088/1748-9326/10/9/095003.

3275 Sue Wing I, Monier E, Stern A, Mundra A (2015) US major crops’ uncertain climate change  
3276 risks and greenhouse gas mitigation benefits. *Environ Res Lett* 10(11):115002. doi:  
3277 10.1088/1748-9326/10/11/115002.

3278 Sukhinin AI (ed) (2010) *Catastrophic Fires in Siberia*. Sukachov Inst. of Forest SibRAS,  
3279 Krasnoyarsk (in Russian).

3280 Swinnen J, Burkitbayeva S, Schierhorn F, Prishchepov AV, Müller D (2017) Production  
3281 Potential in The ‘bread Baskets’ of Eastern Europe and Central Asia. *Global Food Security*  
3282 May 2017. <https://doi.org/10.1016/j.gfs.2017.03.005>

3283 Syromyatina MV, Kurochkin YN, Bliakharskii DP Chistyakov KV (2015) Current dynamics  
3284 of glaciers in the Tavan Bogd Mountains (Northwest Mongolia). *Environ Earth Sci*  
3285 74(3):1905–1914. doi: 10.1007/s12665–015–4606–1.

3286 Syromyatina MV, Kurochkin YN, Chistyakov K, Ayurzana C (2014) Current state and  
3287 changes of glaciers in the Tavan Bogd Mountains (Mongolia). *Ice and Snow* 2014(3):31–  
3288 38 (in Russian). doi: 10.15356/2076–6734–2014–3–31–38.

3289 Tchebakova NM, Parfenova EI (2012) The 21st century climate change effects on the forests  
3290 and primary conifers in central Siberia. *Bosque* 33(3): 253–259. doi: 10.4067/S0717–  
3291 92002012000300004.

3292 Tchebakova NM, Parfenova EI (2013) Potential land cover change in Siberia predicted by  
3293 Siberian bioclimatic model. Section 5.6.2 in Groisman PY, Gutman G (eds) *Regional*  
3294 *Environmental changes in Siberia and their global consequences*. Springer, Heidelberg–  
3295 New York–Dordrecht –London.

3296 Tchebakova NM, Parfenova EI Blyakharchuk TA (2012) Predicted and observed climate-  
3297 induced fire in the Altai-Sayan Mts, Central Asia, during the Holocene. In: Spano D,  
3298 Bacciu V, Salis M, Sirca C (eds) *Modelling Fire Behavior and Risk. A forecast and*  
3299 *prevention system for climate change impacts on risk variability for wildlands and urban*  
3300 *areas*. Nuova StampaColor Industria Grafica Zona Industriale Muros 07030 Muros Sassari,  
3301 Italy.

3302 Tchebakova NM, Parfenova EI, Lysanova GI, Soja AJ (2011) Agroclimatic potential across  
3303 central Siberia in an altered twenty-first century. *Environ. Res. Lett.* 6(4):045207, doi:  
3304 10.1088/1748–9326/6/4/045207.

3305 Tchebakova NM, Parfenova EI, Korets MA, Conard SG (2016b) Potential change in forest  
3306 types and stand heights in central Siberia in a warming climate. *Environ. Res.*  
3307 Lett. 11(3):035016. doi: 10.1088/1748–9326/11/3/035016.

3308 Tchebakova NM, Rehfeldt GE, Parfenova EI (2010) From vegetation zones to climatypes:  
3309 Effects of climate warming on Siberian ecosystems. In: Osawa A., Zyryanova OA,  
3310 Matsuura Y, Kajimoto T, Wein RW (eds) *Permafrost Ecosystems: Siberian Larch Forest.*  
3311 *Ecological Studies* 209, Springer, Heidelberg-New York- Dordrecht –London. doi:  
3312 10.1007/978–1–4020–9692–8.

3313 Tchebakova NM, Parfenova EI, Soja AJ (2009) The effects of climate, permafrost and fire on  
3314 vegetation change in Siberia in a changing climate. *Environ Res Lett* 4(4):045013. doi:  
3315 10.1088/1748–9326/4/4/045013.

3316 Tchebakova NM, Parfenova EI, Soja AJ (2016a) Significant Siberian vegetation change is  
3317 inevitably brought on by the changing climate. In: Mueller L, Sheudshen AK, Eulensteine F  
3318 (eds) *Novel Methods for Monitoring and Managing Land and Water Resources in Siberia.*  
3319 Springer, Dordrecht. ISBN: 978–3–319–24407–5.

3320 Thompson DWJ, Wallace JM (1998) The Arctic oscillation signature in the wintertime  
3321 geopotential height and temperature fields. *Geophys Res Lett* 25 (9):1297–1300.

3322 Tilinina N, Gulev SK, Rudeva I, Koltermann P (2013) Comparing cyclone life cycle  
3323 characteristics and their interannual variability in different reanalyses. *J Climate* 26:6419–  
3324 6438.

3325 Tinner W, Lotter AF (2001) Central European vegetation response to abrupt climate change at  
3326 8.2 ka. *Geology* 29(6):551–554. doi: 10.1130/0091–  
3327 7613(2001)029<0551:CEVRTA>2.0.CO;2.

3328 Troy TJ, Sheffield J, Wood EF (2012) The role of winter precipitation and temperature on  
3329 northern Eurasian streamflow trends. *J Geophys Res – Atmos* 117(D5):D05131. doi:  
3330 10.1029/2011JD016208.

3331 Trueblood MA, Arnade C. (2001) Crop Yield Convergence: How Russia's Yield Performance  
3332 Has Compared to Global Yield Leaders. *Comparat Econom Studies* 43(2):59–81. doi:  
3333 10.1057/ces.2001.8.

3334 Udra IF (1988) Setting and migration of woody plants in temperate belt of Eurasia. *Naukova  
3335 Dumka*, Kiev, Ukraine (in Russian).

3336 Ukrstat (2016) Agriculture of Ukraine in 1990–2014. (Silske Gospodarstvo Ukrayny u 1990–  
3337 2016 roci). A set of statistical yearbooks. State Committee of Statistics of Ukraine, Kyiv.

3338 Unger-Shayesteh K, Vorogushyn S, Farinotti D, Merz B (2013) What do we know about past  
3339 changes in the water cycle of Central Asian headwaters ? A review. *Global and Planetary  
3340 Change* 110:4–25.

3341 Valendik EN, Kisilyakhov EK, Kosov IV, Lobanov AI, Ponomarev EI (2015) Catastrophic  
3342 steppe fires: problems and ways of their solutions. Monitoring, modelling and forecast of  
3343 dangerous natural phenomena and urgent situations. 2015:34–36 (In Russian).

3344 Valendik EN, Kisilyakhov EK, Ryzhkova VA, Ponomarev EI, Goldammer JG (2014) Forest  
3345 fires under anomaly weather conditions in Central Siberia. *Siberian Forest Journal* 3:43–  
3346 52.

3347 <http://сибирскийлеснойжурнал.рф/upload/iblock/50c/50cdf195672d6700b7cbba67f3054032.pdf> (In Russian).

3349 van den Werf GR, Randerson JT, Giglio L, Collatz GJ, Mu M, Kasibhatla PS, Morton DC,  
3350 DeFries RS, Jin Y, van Leeuwen TT (2010) Global fire emissions and the contribution of  
3351 deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmos Chem Phys*  
3352 10(23):11707–11735. doi: 10.5194/acp-10-11707-2010.

3353 Vandergert P, Newell J (2003) Illegal logging in the Russian Far East and Siberia. *Int*  
3354 *Forestry Rev* 5(3):303–306.

3355 van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram  
3356 T, Krey V, Lamarque J-F, Masui T, Meinshausen M, Nakicenovic N (2011) The  
3357 representative concentration pathways: an overview. *Climatic Change* 109(1–2):5–31. doi:  
3358 10.1007/s10584–011–0148-z.

3359 van Vuuren DP, Eickhout B, Lucas PL den Elzen MGJ (2006) Long-term multi-gas scenarios  
3360 to stabilize radiative forcing — exploring costs and benefits within an integrated  
3361 assessment framework. *The Energy J.* 1 27:201–233. <http://www.jstor.org/stable/23297082>.

3362 van Vuuren DP, den Elzen MGJ, Lucas PL, Eickhout B, Strengers BJ, van Ruijven B,  
3363 Wonink S, van Houdt R (2007) Stabilizing greenhouse gas concentrations at low levels: an  
3364 assessment of reduction strategies and costs. *Climatic Change* 81(2):119–159. doi:  
3365 10.1007/s10584–006–9172–9.

3366 Vasileva A, Moiseenko K (2013) Methane emissions from 2000 to 2011 wildfires in  
3367 Northeast Eurasia estimated with MODIS burned area data. *Atm Env* 71:115–121. doi:  
3368 10.1016/j.atmosenv.2013.02.001.

3369 Velichko AA (ed) (2002) Dynamic of Terrestrial Landscape Components and Inner Marine  
3370 Basins of Northern Eurasia during the Last 130 000 years (Atlas-monograph). GEOS,  
3371 Moscow.

3372 Velichko AA, Borisova OK., Zelikson EM, Morozova TD (2004) Changes in vegetation and  
3373 soils of the East European plain to be expected in the 21<sup>st</sup> century due to anthropogenic  
3374 changes in climate. *Geographia Polonica* 77(2):37–45.  
3375 [http://rcin.org.pl/igipz/Content/80/77\\_2\\_calosc.pdf](http://rcin.org.pl/igipz/Content/80/77_2_calosc.pdf).

3376 Velicogna I, Wahr J (2013) Time-variable gravity observations of ice sheet mass balance:  
3377 Precision and limitations of the GRACE satellite data. *Geophys Res Lett* 40(12):3055–  
3378 3063. doi: 10.1002/grl.50527.

3379 Vestreng V, Myhre G, Fagerli H, Reis S, Tarrasó L (2007) Twenty-five years of continuous  
3380 sulphur dioxide emission reduction in Europe. *Atmos Chem Phys* 7(13):3663–3681. doi:  
3381 10.5194/acp-7-3663-2007.

3382 Vinnikov KY, Groisman PY, Lugina KM (1990) Empirical data on contemporary global  
3383 climate changes (temperature and precipitation). *J Climate* 3(6):662–677.

3384 Voinova VD, Zakharova OD, Rybakovsky LL (1993) Contemporary Russian North and its  
3385 Population. In: Rybakovsky LL (ed) *Social and Demographic Development of Russian*  
3386 *North*. Institute of Social and Economic Problems of Population, RAS, Moscow (in  
3387 Russian).

3388 Volodin EM (2013) The mechanism of multidecadal variability in the Arctic and North  
3389 Atlantic in climate model INMCM4. *Environ Res Lett* 8(3):035038. doi: 10.1088/1748–  
3390 9326/8/3/035038

3391 Volodin EM, Diansky NA, Gusev AV (2013) Simulation and prediction of climate changes in  
3392 the 19th to 21st centuries with the Institute of Numerical Mathematics, Russian Academy  
3393 of Sciences, model of the Earth's climate system. *Izvestia Atmospheric and Oceanic*  
3394 *Physics* 49(4):347–366. doi: 10.1134/s0001433813040105.

3395 Voronin VI, Shubkin RG (2007) Analysis of the long-term chronologies of forest fires and  
3396 forecast of fire activity in the Baikal region. *Fire safety* 3:64–70 (in Russian).

3397 Walker DA, Pierce JL (eds) (2015) *Rapid Arctic Transitions due to Infrastructure and Climate*  
3398 (RATIC): A contribution to ICARPIII. Alaska Geobotany Center Publ AGC 15– 02. Univ  
3399 Alaska-Fairbanks, Fairbanks, Alaska.

3400 Warneke C, Bahreini R, Brioude J, Brock CA, de Gouw, JA, Fahey DW, Froyd KD,  
3401 Holloway JS, Middlebrook A, Miller L, Montzka S, Murphy DM, Peischl J, Ryerson TB,  
3402 Schwarz JP, Spackman JR, Veres P (2009) Biomass burning in Siberia and Kazakhstan as  
3403 an important source for haze over the Alaskan Arctic in April 2008. *Geophys Res Lett*  
3404 36(2):L02813. doi: 10.1029/2008GL036194.

3405 Weyant J, Davidson O, Dowlabathi H, Edmonds J, Grubb M, Parson EA, Richels R, Rotmans  
3406 J, Shukla PR, Tol RSH, Cline W (1996) Integrated assessment of climate change: an  
3407 overview and comparison of approaches and results. Cambridge University Press,  
3408 Cambridge, United Kingdom, New York, USA.

3409 White D, Hinzman L, Alessa L, Cassano J, Chambers M, Falkner K, Francis J, Gutowski WJ  
3410 Jr, Holland M, Holmes RM, Henry Huntington H, Kane D, Kliskey A, Lee C, McClelland  
3411 J, Peterson B, Rupp, TS, Straneo F, Steele M, Woodgate R, Yang D, Yoshikawa K, Zhang  
3412 T (2007) The arctic freshwater system: Changes and impacts. *J Geophys Res*  
3413 Biogeosciences 112(G4): G04S54. doi: 10.1029/2006JG000353.

3414 Williams J (2013) Exploring the onset of high-impact mega-fires through a forest land  
3415 management prism. *Forest Ecology and Management* 294: 4–10.

3416 Wise M, Calvin K, Thomson A, Clarke L, Bond-Lamberty B, Sands R, Smith SJ, Janetos A,  
3417 Edmonds J (2009) Implications of limiting CO<sub>2</sub> concentrations for land use and energy.  
3418 *Science* 324(5931):1183–1186. doi: 10.1126/science.1168475.

3419 Woo M-K (2012) *Permafrost Hydrology*. Springer-Verlag, Berlin.

3420 World Glacier Monitoring Service (WGMS) (2015) *Global Glacier Change Bull.* 1 (2012–  
3421 2013). Zemp M, Gärtner-Roer I, Nussbaumer SU, Hüsler F, Machguth H, Mölg N, Paul F,  
3422 Hoelzle M (eds.) ICSU(WDS)/IUGG(IACS)/ UNEP/UNESCO/WMO, Zurich,  
3423 Switzerland. doi: 10.5904/wgms-fog-2015–11.

3424 Wright CK, de Beurs KM, Henebry GM (2012) Combined analysis of land cover change and  
3425 NDVI trends in the Northern Eurasian grain belt. *Frontiers in Earth Science* 6(2):177–187.  
3426 [doi: 10.1007/s11707-012-0327-x](https://doi.org/10.1007/s11707-012-0327-x).

3427 Wright CK, de Beurs KM, Henebry GM (2014) Land surface anomalies preceding the 2010  
3428 Russian heat wave and a link to the North Atlantic Oscillation. *Environ Res Lett*  
3429 9(12):124015. [doi: 10.1088/1748-9326/9/12/124015](https://doi.org/10.1088/1748-9326/9/12/124015).

3430 Wu T, Zhao L, Li R, Wang Q, Xie C, Pang Q (2013) Recent ground surface warming and its  
3431 effects on permafrost on the central Qinghai-Tibet Plateau. *Int J Climatol* 33(4):920–930.  
3432 [doi: 10.1002/joc.3479](https://doi.org/10.1002/joc.3479).

3433 Xi X, Sokolik IN (2015a) Dust interannual variability and trend in Central Asia from 2000 to  
3434 2014 and their climatic linkages. *J Geophys Res – Atmos* 120(23):12175–12197. doi:  
3435 [10.1002/2015JD024092](https://doi.org/10.1002/2015JD024092)

3436 Xi X, Sokolik IN (2015b) Seasonal dynamics of threshold friction velocity and dust emission  
3437 in Central Asia. *J Geophys Res – Atmos* 120(4):1536–1564. Doi: [10.1002/2014JD022471](https://doi.org/10.1002/2014JD022471)

3438 Xuan J, Liu GL, Du K (2000) Dust emission inventory in Northern China. *Atmos Environ*  
3439 34(26):4565–4570.

3440 Yang D, Ye B, Shiklomanov A (2004) Discharge characteristics and changes over the Ob  
3441 River watershed in Siberia. *J Hydrometeorol* 5(4):595–610. doi: [10.1175/1525-7541\(2004\)005<0595:DCACOT>2.0.CO;2](https://doi.org/10.1175/1525-7541(2004)005<0595:DCACOT>2.0.CO;2).

3443 Yue C, Ciais P, Zhu D, Wang T, Peng SS, Piao SL (2016) How have past fire disturbances  
3444 contributed to the current carbon balance of boreal ecosystems? *Biogeosciences* 13:675–  
3445 690. doi: [10.5194/bg-13-675-2016](https://doi.org/10.5194/bg-13-675-2016).

3446 Zaehle S, Jones CD, Houlton B, Lamarque J-F, Robertson E (2015) Nitrogen availability  
3447 reduces CMIP5 projections of twenty-first-century land carbon uptake. *J Climate* 28:2494–  
3448 2511. doi: [10.1175/JCLI-D-13-00776.1](https://doi.org/10.1175/JCLI-D-13-00776.1).

3449 Zhai PM, Chao Q, Zou X (2004) Progress in China's climate change study in the 20<sup>th</sup> century.  
3450 J Geograph Sci (English version of *Acta Geographica Sinica*) 14(suppl 2004):3–11.  
3451 Available at: <http://www.geog.cn>.

3452 Zhang N, Yasunari T, Ohta T (2011) Dynamics of the larch taiga–permafrost coupled system  
3453 in Siberia under climate change. Environ Res Lett 6(2):024003. doi: 10.1088/1748–  
3454 9326/6/2/024003.

3455 Zhang X, Ermolieva T, Balkovic J, Mosnier A, Kraxner F, Liu J (2015) Recursive cross-  
3456 entropy downscaling model for spatially explicit future land uses: A case study of the  
3457 Heihe River Basin. Physics and Chemistry of the Earth Parts A/B/C 89:56–64. doi:  
3458 10.1016/j.pce.2015.05.007

3459 Zhang X, He J, Zhang J, Polyakov I, Gerdes R, Inoue J, Wu P (2012a) Enhanced poleward  
3460 moisture transport and amplified northern high-latitude wetting trend. Nature Climate  
3461 Change 3: 47–51. doi: 10.1038/NCLIMATE1631

3462 Zhang Y, Sachs T, Li C, Boike J, (2012b) Upscaling methane fluxes from closed chambers to  
3463 eddy covariance based on a permafrost biogeochemistry integrated model. Glob Change  
3464 Biol 18(4):1428–1440. doi: 10.1111/j.1365–2486.2011.02587.x.

3465 Zhao TT, Bergen KM, Brown DG, Shugart HH (2009) Scale dependence in quantification of  
3466 land-cover and biomass change over Siberian boreal forest landscapes. *Landscape*  
3467 *Ecology*, **24**, 1299–1313.

3468 Zhu Q, Zhuang Q (2013) Modeling the effects of organic nitrogen uptake by plants on the  
3469 carbon cycling of boreal ecosystems. Biogeosciences 10:7943–7955. doi: 10.5194/bg-10–  
3470 7943–2013.

3471 Zhu Q, Zhuang Q, Gao X, Sokolov A, Schlosser CA (2013) Pan-Arctic land-atmospheric  
3472 fluxes of methane and carbon dioxide in response to climate change over the 21st century.  
3473 Environ Res Lett 8(4):045003. doi: 10.1088/1748–9326/8/4/045003.

3474 Zhu Q, Zhuang Q, Lu X, Song L (2014) Spatial scale-dependent land-atmospheric methane  
3475 exchanges in the northern high latitudes from 1993 to 2004. *Biogeosciences* 11:1693–  
3476 1704. doi: 10.5194/bg-11–1693–2014.

3477 Zhuang Q, Chen M, Xu K, Tang J, Saikawa E, Lu Y, Melillo JM, Prinn RG McGuire AD  
3478 (2013) Response of global soil consumption of atmospheric methane to changes in  
3479 atmospheric climate and nitrogen deposition. *Global Biogeochem Cycles* 27(3):650–663.  
3480 doi: 10.1002/gbc.20057.

3481 Zickfeld KM, Eby M, Weaver AJ, Alexander K, Crespin E, Edwards NR, Eliseev AV,  
3482 Feulner G, Fichefet T, Forest CE, Friedlingstein P, Goosse H, Holden PB, Joos F,  
3483 Kawamiya M, Kicklighter D, Kienert H, Matsumoto K, Mokhov II, Monier E, Olsen SM,  
3484 Pedersen JOP, Perrette M, Philippon-Berthier G, Ridgwell A, Schlosser A, Schneider Von  
3485 Deimling T, Shaffer G, Sokolov A, Spahni R, Steinacher M, Tachiiri K, Tokos KS,  
3486 Yoshimori M, Zeng N, Zhao F (2013): Long-term climate change commitment and  
3487 reversibility: an EMIC intercomparison. *J Climate* 26:5782–5809. doi: 10.1175/JCLI-D-  
3488 12–00584.1.

3489 Ziolkowska E, Ostopowicz K, Radeloff VC, Kuemmerle T (2014) Effects of different matrix  
3490 representations and connectivity measures on habitat network assessments. *Landscape  
3491 Ecology* 29(9):1551–1570. doi: 10.1007/s10980–014–0075–2.

3492 Zuev VV, Semenov VA, Shelekhova EA, Gulev SK, Koltermann P (2012) Evaluation of the  
3493 impact of oceanic heat transport in the North Atlantic and Barents Sea on the Northern  
3494 Hemispheric climate. *Doklady Earth Sciences*, 445(2):1006–1010. doi:  
3495 10.1134/S1028334X12080181.

3496 **Figure legends**

3497

3498 **Figure 1.** The NEESPI study area is loosely defined as the region between 15°E in the west,  
3499 the Pacific Coast in the east, 40°N in the south, and the Arctic Ocean coastal zone in the  
3500 north. On this map, green corresponds to vegetated lands. Light brown and yellow indicate  
3501 sparse vegetation and arid areas, respectively (Groisman et al. 2009). Major city names within  
3502 the NEESPI domain (shown in Groisman et al. 2009) are removed. During the NEESPI  
3503 studies, we expand the study domain occasionally to address the ecosystem in its entirety  
3504 beyond the strict lat/long boundaries (e.g., taiga and tundra zones in Fennoscandia or barren  
3505 and semi-desert areas in China. The Dry Land Belt of Northern Eurasia is sketched on the  
3506 map by a dashed white line.

3507 **Figure 2.** Global annual surface air temperature anomalies (°C) derived from the  
3508 meteorological station data for the 1957–2016 period (Lugina et al. 2006, updated). This time  
3509 series is based upon the land-based surface air temperature station data with a processing  
3510 algorithm developed 25 years ago by Vinnikov et al. (1990). The reference period used for  
3511 calculations of anomalies is 1951–1975. Dotted ovals in the figure show (a) this reference  
3512 period, (b) the new state of the global Earth system (+0.3° to 0.4°C of the global temperature)  
3513 with shift during the late 1970s and early 1980s, that manifested itself in biospheric, oceanic,  
3514 cryospheric, and atmospheric variables around the World (Reid et al. 2016), and (c) the last  
3515 period (since circa 2001) , when impacts on the Earth system (e.g., retreat of the cryosphere,  
3516 Arctic warming, increasing dryness of interior of the continents) still need to be completely  
3517 documented.

3518 **Figure 3.** Seasonal temperature anomalies over Northern Eurasia (the NEESPI study domain)  
3519 for the 1881–2016 period. The reference period used for calculations of anomalies is 1951–

3520 1975. The annual anomaly for 2016 is +2.0°C. Linear trend estimates shown by dash lines  
3521 are provided for demonstration purposes only. Data source: archive of Lugina et al. (2006  
3522 updated).

3523 **Figure 4.** Vegetation distribution under present climate conditions and equilibrium vegetation  
3524 distribution under future climate conditions (scenarios) over Northern Eurasia in current  
3525 climate and by the year 2090 as calculated by the RuBCliM ecosystem model (developed by  
3526 modifying the SibCliM ecosystem models, Tchebakova et al. 2009, 2010, 2016a) using an  
3527 ensemble of Canadian (CGCM3.1), UK (HadCM3) and French (IPCLCM4) GCM outputs  
3528 for the B1 and A2 scenarios for the IPCC Fourth Assessment Report (Core Writing Team  
3529 2007), where greenhouse gases induced global warming of 3 –5°C and 6 – 8°C, respectively,  
3530 by 2090 (Tchebakova et al. 2016a).

3531 **Figure 5. Left.** Annual surface air temperature anomalies (°C) area-averaged over the 60°N -  
3532 90°N latitudinal zone (Lugina et al. 2006, updated). **Right.** September Arctic sea ice extent,  
3533 SIE,  $10^6$  km<sup>2</sup> (U.S. National Snow & Ice Data Center, Boulder, Colorado, USA web-site,  
3534 <http://nsidc.org/data>; date of retrieval; Dec. 30, 2015). For possible change in 2016, see  
3535 Gannon (2016). Linear trend estimates shown by dash lines are provided for demonstration  
3536 purposes only.

3537 **Figure 6.** Examples of fire-induced forest transformations in the light-coniferous (Scots pine  
3538 and larch) forests of southern Siberia when logging and plantation are done: (a) unburned  
3539 forest; (b) forest burned by low-severity fire with high trees survival; (c) forest burned by  
3540 high-severity fire with high tree mortality; (d) repeatedly-burned forest with all trees killed  
3541 and almost all organic layer consumed; (e) logging after post-fire tree mortality; (f) repeatedly  
3542 burned and logged forest site, with little to no tree regeneration, dominated by tall grasses; (g)  
3543 plantation of Scots pine on a repeatedly-disturbed site with no natural regeneration; (i) burned

3544 plantation; (j) the “question” mark indicates sites where management activities may alter  
3545 these disturbance trajectories in unknown ways (Kukavskaya et al. 2016).

3546 **Figure 7.** Manifestations of the cryosphere retreat: **(a)** Spring snow cover extent anomalies  
3547 over Eurasia (Blunden and Arndt 2016); **(b)** Number of newly emerging thermokarst lakes in  
3548 West Siberia during the 1973–2013 period (Polishchuk et al. 2015); **(c-d)** Altai Mountains on  
3549 the boundary of Russia, China, and Mongolia; Kozlov glacier in 1906 and 2013, respectively  
3550 (Syromyatina et al. 2015).

3551 **Figure 8.** Annual number of deep cyclones with sea surface atmospheric pressure in its center  
3552 less than 980 hPa entering sector [45°N – 50°N; 60°E – 90°E] that encompasses Central Asia  
3553 according to ERA-interim reanalysis (Archive of Tilinina et al. 2013, updated).

3554 **Figure 9.** Changes in the surface water cycle over Northern Eurasia that have been  
3555 statistically significant in the 20<sup>th</sup> century; areas with more humid conditions (**blue**), with  
3556 more dry conditions (**red**), with more agricultural droughts (**circles and ovals**), and with  
3557 more prolonged dry episodes (**rectangles**) (Groisman et al. 2009, updated). In the  
3558 westernmost region of this map (Eastern Europe), blue and red rectangles overlap indicating  
3559 “simultaneous” (although in different years) increases of heavy rainfall frequency and of  
3560 occurrences of prolonged no-rain periods.

3561 **Figure 10.** Top panel: Annual precipitation and surface air temperature in Siberia (east of the  
3562 Ural Mountains, excluding Chukotka) from 18 Siberian stations and reanalysis fields. Lower  
3563 panel: Total annual river discharge to the Arctic Ocean from the six largest rivers in the  
3564 Eurasian Arctic for the observational period 1936–2014 (Holmes et al. 2015) and annual  
3565 minimum sea ice extent for 1979–2014 (source of the sea ice extent data: U.S. National Snow  
3566 & Ice Data Center, Boulder, Colorado, USA web-site, <http://nsidc.org/data>).

3567 **Figure 11.** Carbon sources and sinks by full carbon account of Russian terrestrial ecosystems  
3568 (average for 2007–2009). Units of sinks and sources are  $\text{g C m}^{-2} \text{ yr}^{-1}$  (Shvidenko and  
3569 Schepaschenko 2014).

3570 **Figure 12.** Major export markets for Russian forest products 1960—2009 (archive of Newell  
3571 and Simeone 2014; data source European Forest Institute 2014).

3572 **Figure 13.** Changes in sown areas across the former Soviet Union (Russia, Ukraine, and  
3573 Kazakhstan) from 1990 to 2013; areas of abandoned sown areas for this period are: 40 Mha in  
3574 Russia (Rosstat 2016); 5.4 Mha in Ukraine (Ukrstat 2014); and 13 Mha in Kazakhstan  
3575 (Kazstat 2014).

3576 **Figure 14.** Land cover change from 2001 to 2012 based on MODIS LC products for the three  
3577 regions within DLB.

3578 **Figure 15.** Land-use and land-cover change in the Asian part of the DLB without steppe  
3579 regions of Siberia from 2001 to 2012 (Qi et al. 2012a, 2012b updated). Two zoomed  
3580 windows show the land-use and land-cover changes between 2001 and 2012 in (A) the  
3581 Central Asia around the Uzbekistan and (B) southern border of the Gobi Desert around  
3582 Lanzhou, China.

3583 **Figure 16.** Almaty urban region in Kazakhstan from DSM satellite observations in 2000  
3584 (left) and 2009 (right), translucently draped over 3D topography. Red represents main urban  
3585 areas, transitioned into orange for urban area with less development, then to yellow for  
3586 suburban, and finally to green for rural/natural/wilderness areas. Blue indicates surface water  
3587 (lakes, reservoirs, etc.). Astounding expansion of the Almaty urban extent occurred between  
3588 2000 and 2009.

3589 **Figure 17.** Dramatic increase in the total building volume corresponding to the real estate  
3590 boom since 2000 in an area of  $\sim 6 \text{ km}^2$  centered in the urban extent of Almaty in 2009 seen in  
3591 red in the right panel of Figure 16. Error bars show the accuracy of regional averaged values

3592 (columns) and incorporate together errors of the observation and area-averaging methods  
3593 used. The linear trend line indicates the mean rate of the building volume increase during the  
3594 study period and its comparison with error bars shows that the changes are clearly seen  
3595 beyond the noise generated by observations and the averaging procedure.

3596 **Figure 18.** The frequency of and monetary losses from the major natural and environmental  
3597 disasters across the globe. Source: Munich Re-insurance NatCatSERVICE  
3598 (<http://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html>).

3599 **Figure 19.** An example schematic of an Integrated Assessment Model (IAM) that couples a  
3600 human activity model and an Earth system model (ESM) with a focus on three feedback  
3601 pathways: health, land-use change, and water resources (from Monier et al. 2017). See text for  
3602 details.

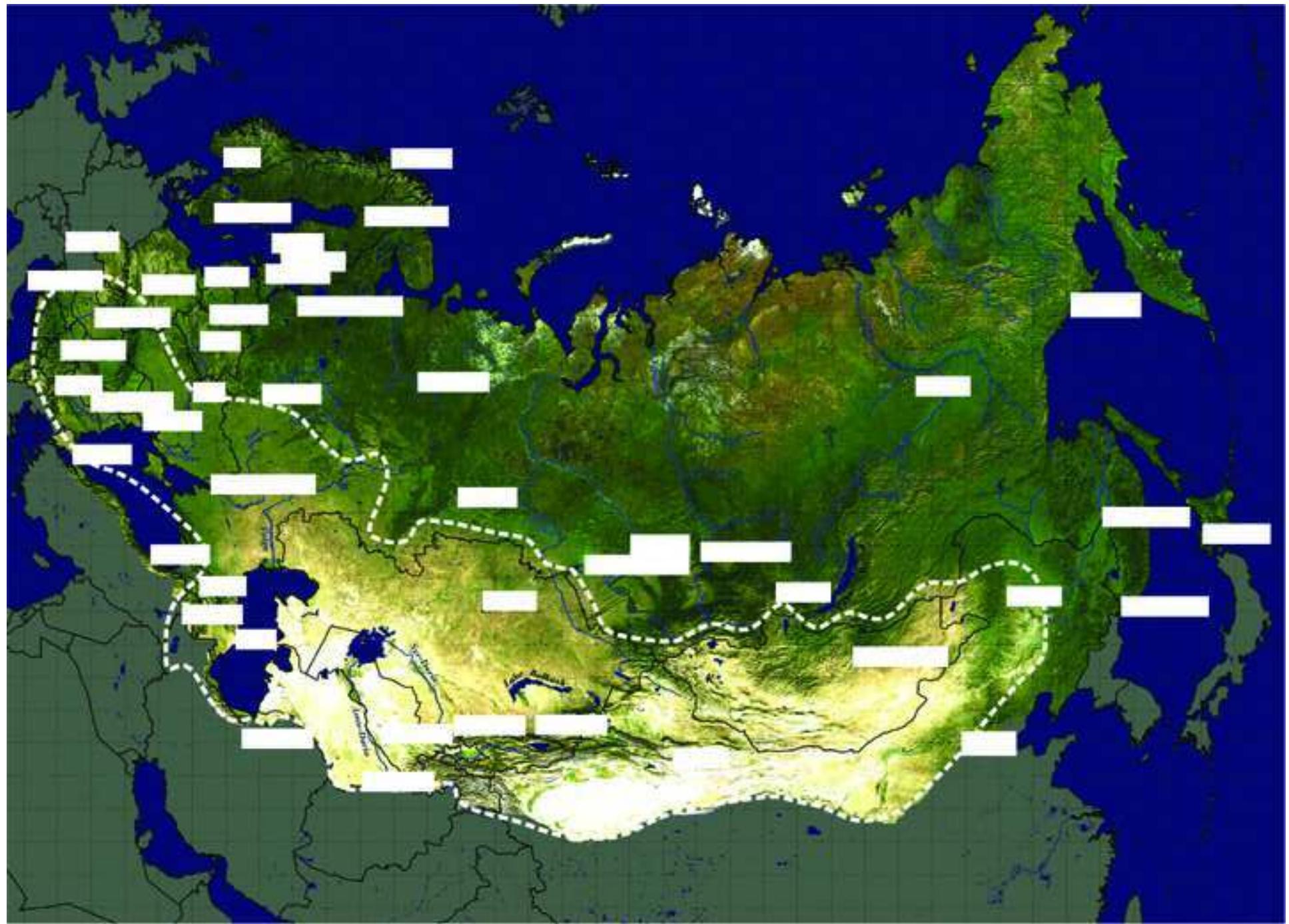
**Table 1**

Non-exhaustive list of modeling studies with a focus on Northern Eurasia. The list is sorted by specific aspects of the Earth and human systems. Some studies are listed under several aspects of the Earth and human systems. From Monier et al. (2017 updated).

<b>Specific aspects of the Earth and human systems</b>	<b>References to modeling studies with a focus on Northern Eurasia</b>
Agriculture (crop modeling, economics)	Dronin and Kirilenko 2010; Gelfan et al. 2012; Iizumi and Ramankutty 2016; Magliocca et al. 2013; Peng et al. 2013; Schierhorn et al. 2014a, 2014b; Tchebakova et al. 2011
Air quality (aerosols, ozone, pollen, dust...)	Baklanov et al. 2013; Darmenova et al. 2009; Lu et al. 2010; Siljamo et al. 2013; Sofiev et al. 2013; Soja et al. 2004; Sokolik et al. 2013; Xi and Sokolik 2015a, 2015b
Carbon (in land and water)	Bohn et al. 2013, 2015; Cresto-Aleina et al. 2015; Dargaville et al. 2002a, 2002b; Dass et al. 2016; Dolman et al. 2012; Gao et al. 2013; Glagolev et al. 2011; Gustafson et al. 2011a; Hayes et al. 2011a, 2011b, 2014; John et al. 2013a; Kicklighter et al. 2013, 2014; Kim et al. 2011; Koven et al. 2011; Kuemmerle et al. 2011a, 2011b; Kurganova et al. 2014, 2015; Lu et al. 2009b; McGuire et al. 2010; Mukhortova et al. 2015; Narayan et al. 2007; Olchev et al. 2009a, 2013a; Rawlins et al. 2015; Rossini et al. 2014; Sabrekov et al. 2014, 2016; Saeki et al. 2013; Schaphoff et al. 2015; Schierhorn et al. 2013; Schulze et al. 2012; Shakhova et al. 2013, 2015; Shuman and Shugart 2009; Shuman et al. 2013a; Yue et al. 2016; Zhang et al. 2012b; Zhao et al. 2009; Zhu et al. 2013, 2014; Zhu and Zhuang 2013; Zhuang et al. 2013
Climate	Anisimov et al. 2013; Arzhanov et al. 2012a, 2012b; Miao et al. 2014;

	Monier et al. 2013; Onuchin et al. 2014; Shahgedanova et al. 2010; Shkolnik and Efimov 2013; Volodin 2013; Volodin et al. 2013; Zuev et al. 2012
Cryosphere (snow, glaciers, sea ice...)	Callaghan et al. 2011a, 2011b; Farinotti et al. 2015; Hagg et al. 2006; Klehmet et al. 2013; Loranty et al. 2014; Mokhov et al. 2013b; Pieczonka and Bolch 2015; Shahgedanova et al. 2010; Shakhova et al. 2015; Sokratov and Shmakin 2013; Sorg et al. 2012
Demography	Heleniak 2015
Energy balance	Brovkin et al. 2006; Gálos et al. 2013; Loranty et al. 2014; Olchev et al. 2009b; Oltchev et al. 2002b; Tchekabakova et al. 2012
Hydrological cycle	Bowling and Lettenmaier 2010; Cresto-Aleina et al. 2015; Gelfan 2011; Georgiadi et al. 2010, 2014a; Hagg et al. 2006; Karthe et al. 2015; Khon and Mokhov 2012; Kicklighter et al. 2013; Klehmet et al. 2013; Kuchment et al. 2011; Liu et al. 2013, 2014, 2015; McClelland et al. 2004; Motovilov and Gelfan 2013; Novenko and Olchev 2015; Olchev et al. 2009a, 2013a; Oltchev et al. 2002a, 2002b; Osadchiev 2015; Rawlins et al. 2010; Serreze et al. 2006; Shiklomanov et al. 2013; Shiklomanov and Lammers 2013; Shkolnik et al. 2017; Sorg et al. 2012; Streletsckiy et al. 2015b; Troy et al. 2012; Zhang et al. 2011
Land-use change	Blyakharchuk et al. 2014; Chen et al. 2017; Griffiths et al. 2013; Gustafson et al. 2011a; Hayes et al. 2011a; Hitztaler and Bergen 2013; Kicklighter et al. 2014; Kraemer et al. 2015; Kuemmerle et al. 2009; Meyfroidt et al. 2016; Peterson et al. 2009; Prishchepov et al. 2013, 2017; Robinson et al. 2013; Schierhorn et al. 2013, 2014a, 2014b; Smaliychuk et al. 2016; Zhang et al. 2015
Infrastructure	Shiklomanov and Streletsckiy 2013; Shiklomanov et al. 2017; Stephenson

	et al. 2011; Streletskei et al. 2012
Nitrogen	Kopáček et al. 2012; Kopáček and Posch 2011; Oulehle et al. 2012; Zhu and Zhuang 2013; Zhuang et al. 2013
Permafrost	Euskirchen et al. 2006; Gao et al. 2013; Gouttevin et al. 2012; Hayes et al. 2014; MacDougall and Knutti 2016; Marchenko et al. 2007; Shakhova et al. 2013, 2015; Shkolnik et al. 2012b; Streletskei et al. 2012, 2015b; Zhang et al. 2011
Terrestrial ecosystems characteristics	Cresto-Aleina et al. 2013; Kopačková et al. 2014, 2015; Lapenis et al. 2005; Lebed et al. 2012; Li et al. 2016; Shuman et al. 2013a, 2013b; Shuman and Shugart 2012; Ziolkowska et al. 2014
Vegetation shifts	Gustafson et al. 2011a; Jiang et al. 2012, 2016; Khvostikov et al. 2015; Kicklighter et al. 2014; Li et al. 2014; Macias-Fauria et al. 2012; Novenko et al. 2014; Schaphoff et al. 2015; Shuman et al. 2015; Soja et al. 2007; Tchebakova et al. 2009, 2010, 2016a, 2016b; Tchebakova and Parfenova 2012; Velichko et al. 2004
Weather (i.e. extreme events)	Barriopedro et al. 2011; Meredith et al. 2015; Mokhov et al. 2013a; Schubert et al. 2014; Shkolnik et al. 2012a
Wildfire	Balshi et al. 2007; Dubinin et al. 2011; Gustafson et al. 2011b; Kantzas et al. 2013; Loboda and Csiszar 2007; Malevsky-Malevich et al. 2008; Narayan et al. 2007; Park and Sokolik 2016; Schulze et al. 2012; Soja et al. 2004; Tchebakova et al. 2009, 2012; Vasileva and Moiseenko 2013
Zoology	Bragina et al. 2015; Kuemmerle et al. 2011a, 2014; Ziolkowska et al. 2014



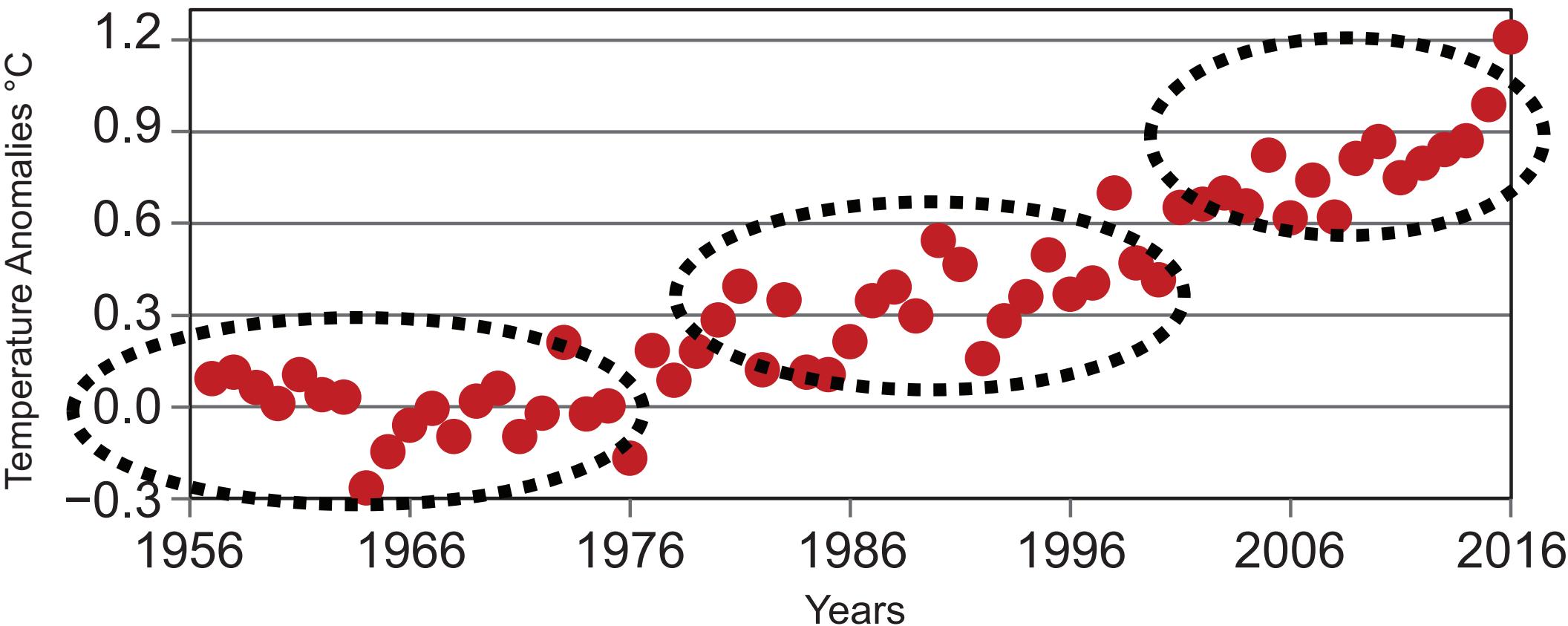
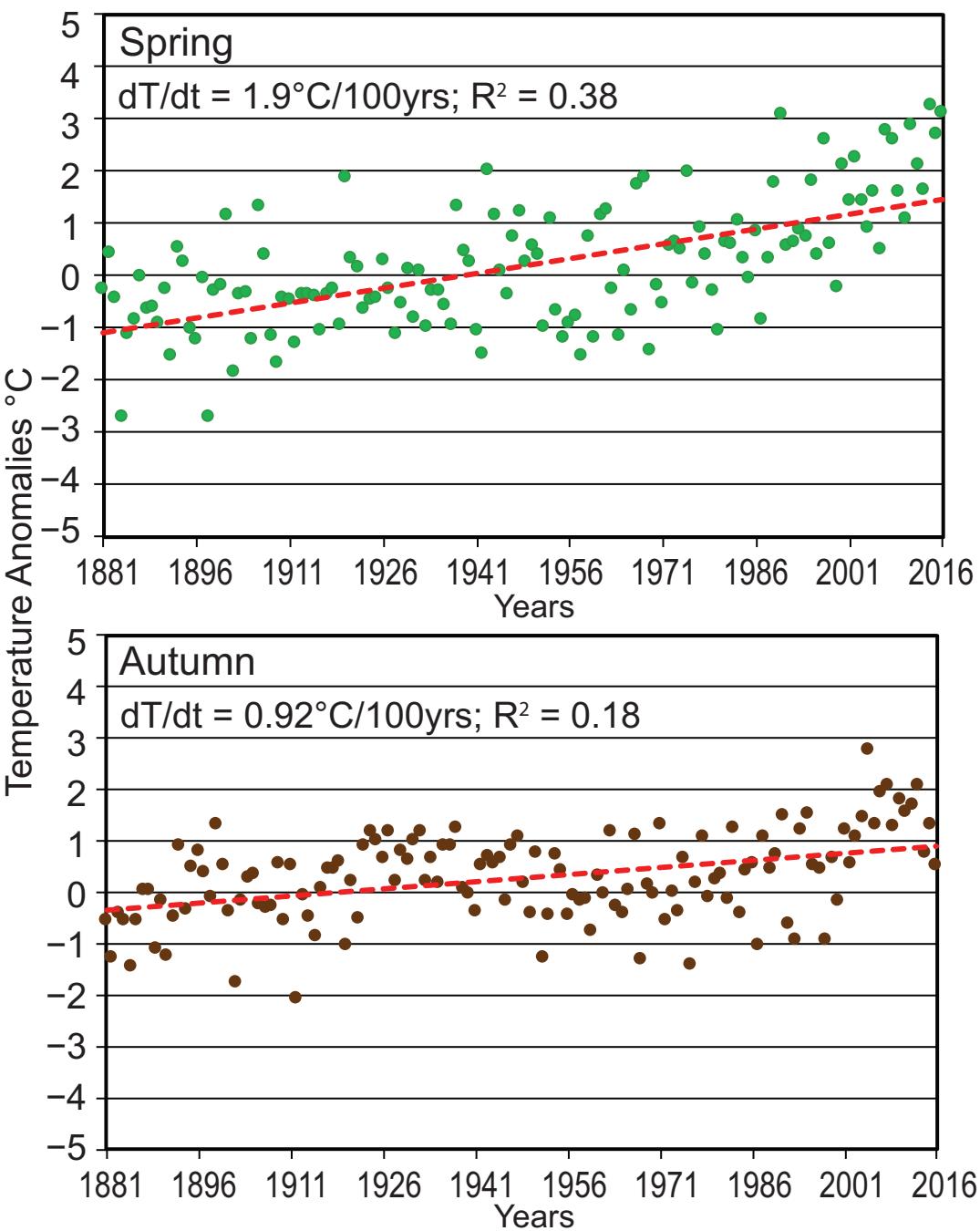
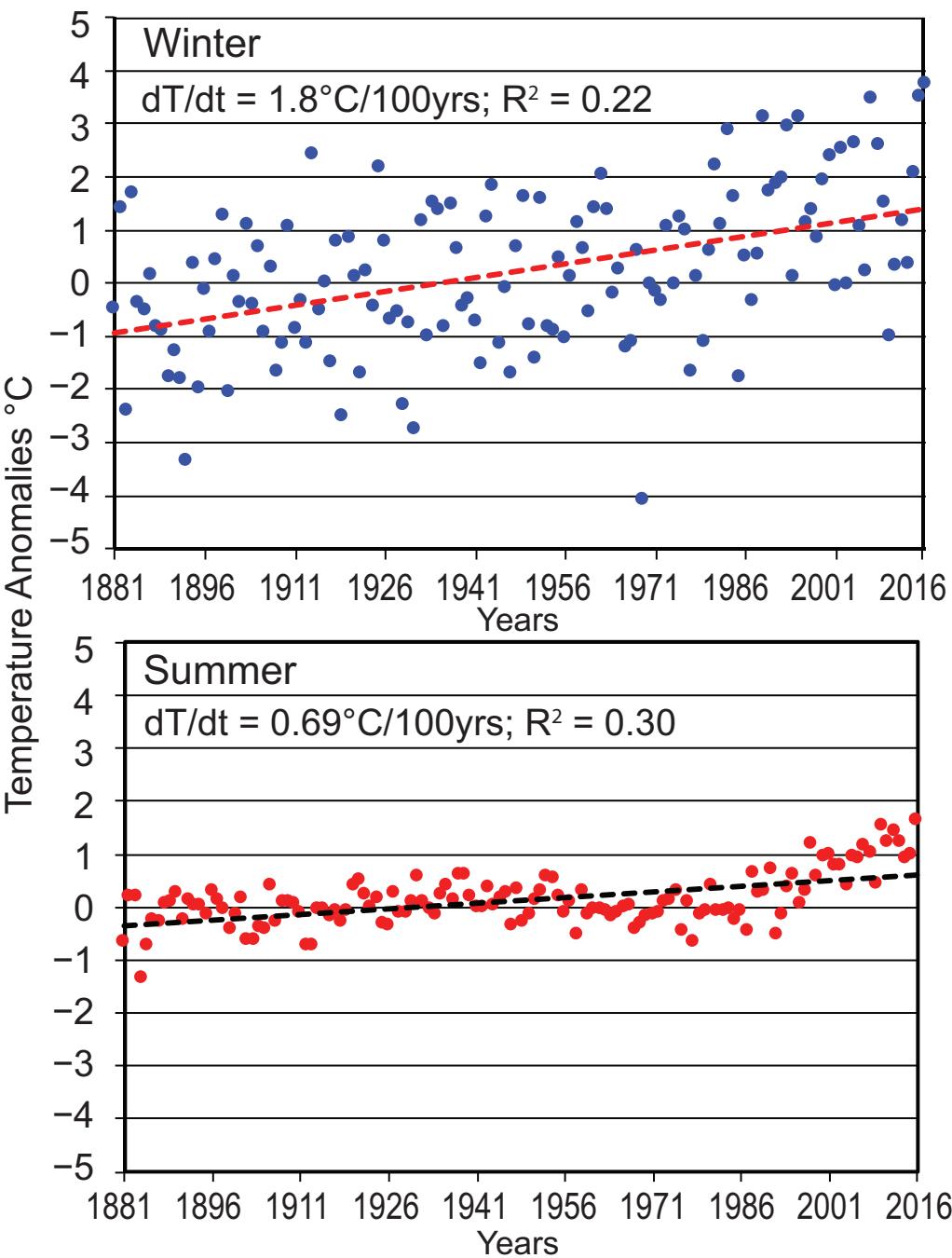
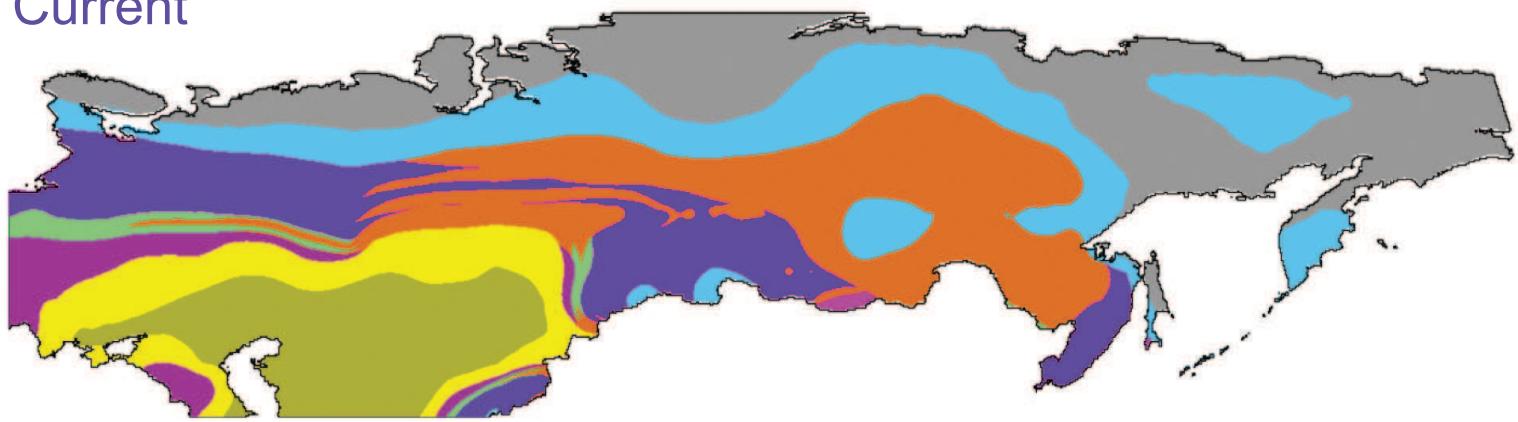


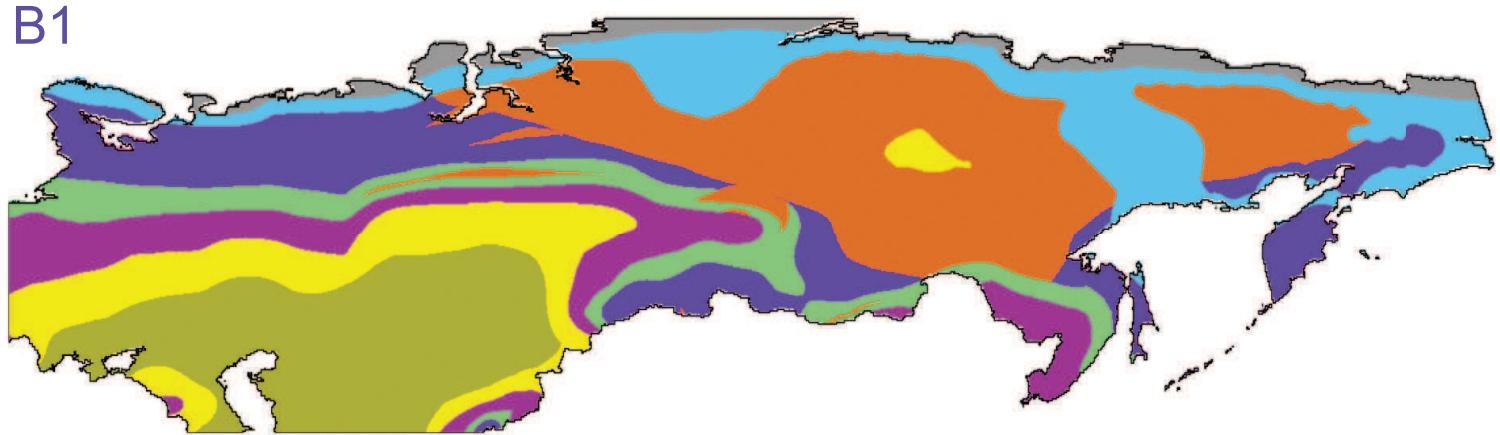
Figure 3

[Click here to download Figure Figure\\_03-final.eps](#)


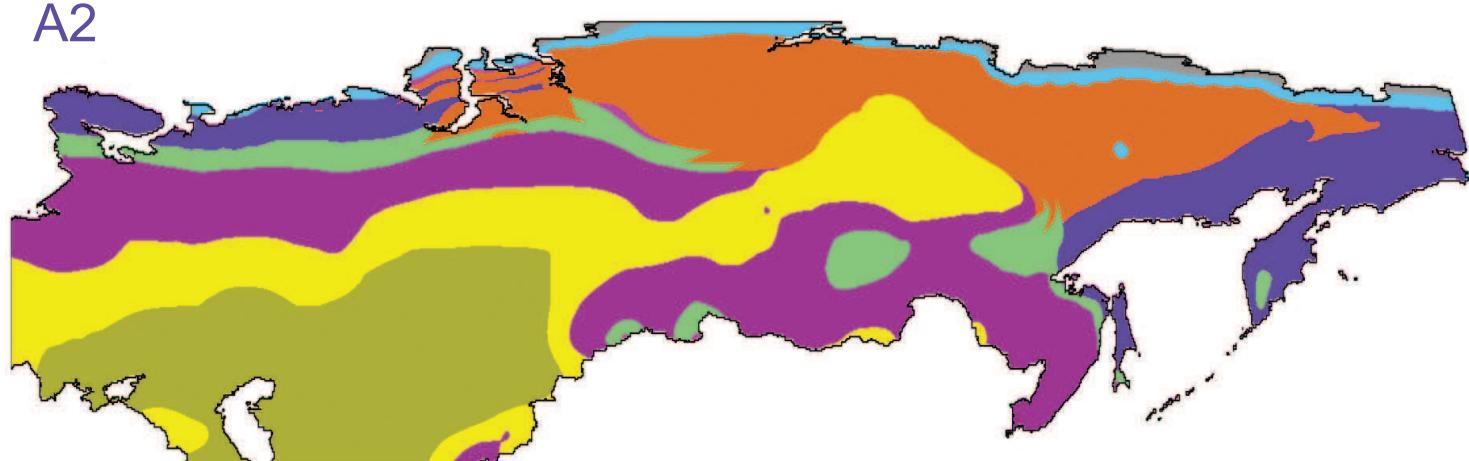
Current



B1



A2



#### Vegetation classes

	Tundra		Mixed
	Forest-Tundra		Broad-leaved
	Dark Taiga		Steppe
	Light Taiga		Semidesert

Figure 5

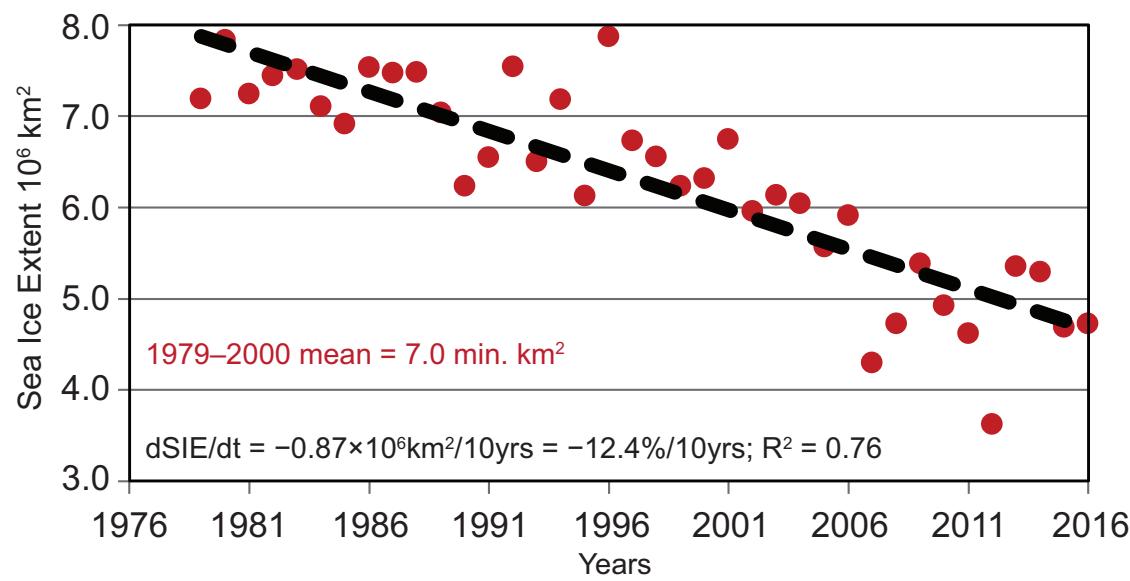
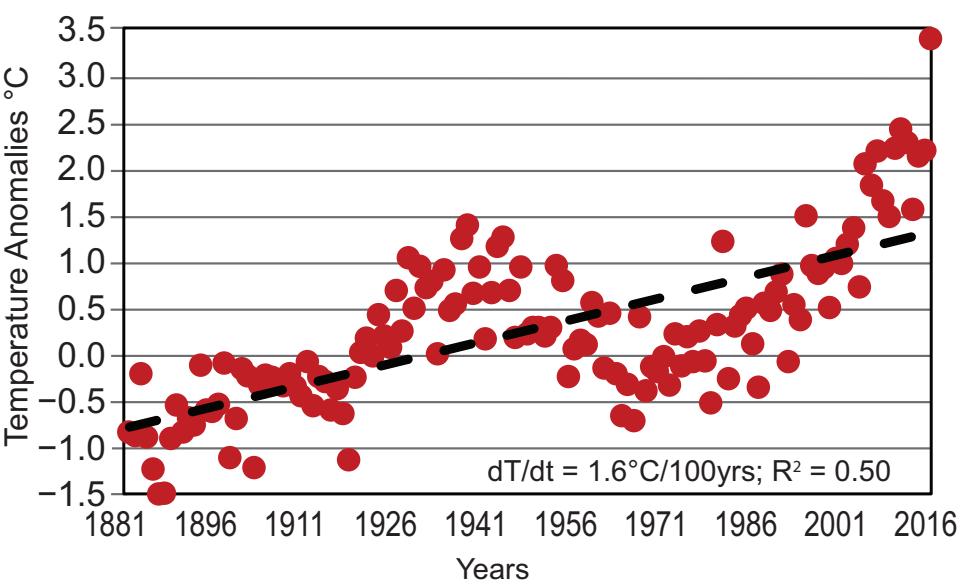
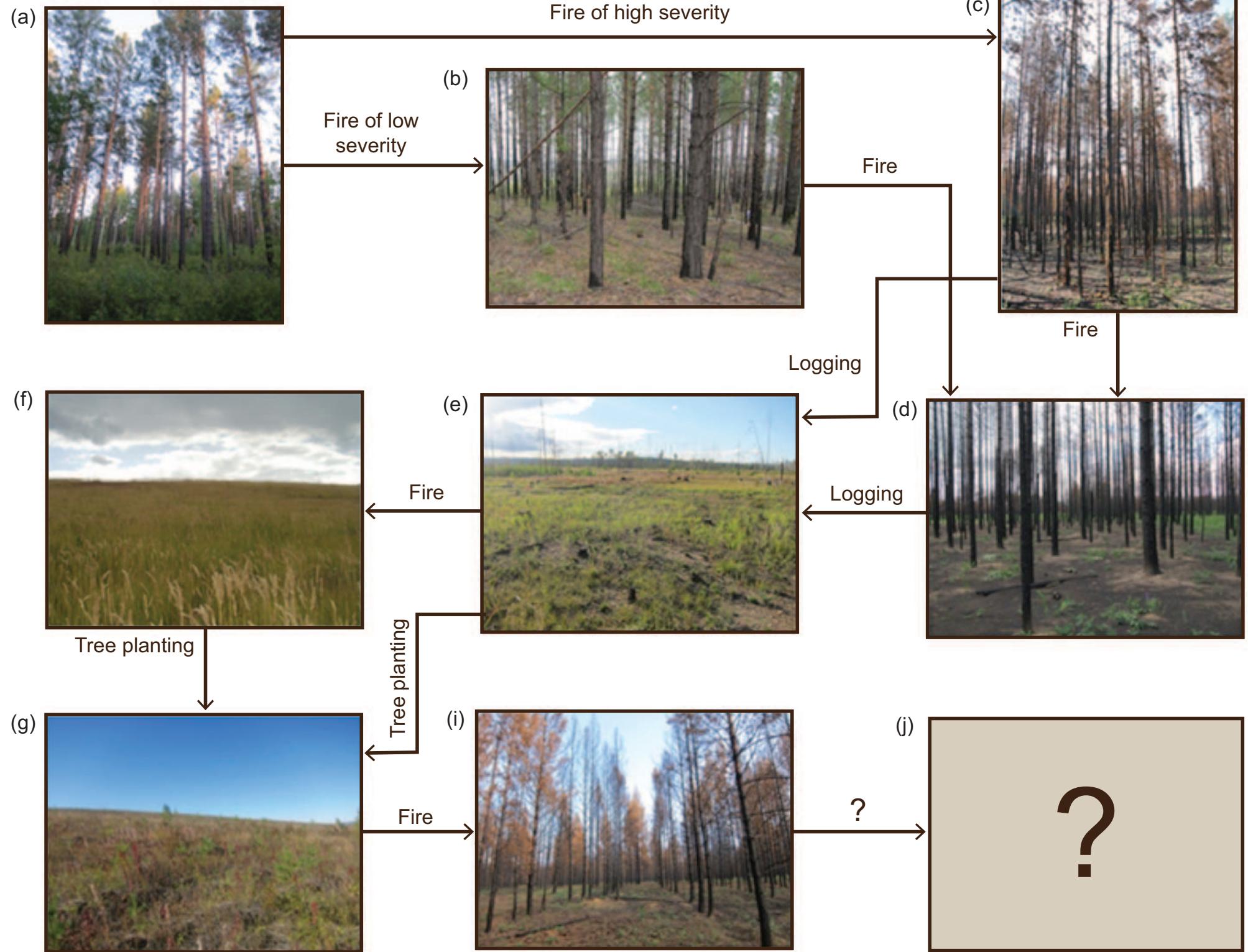
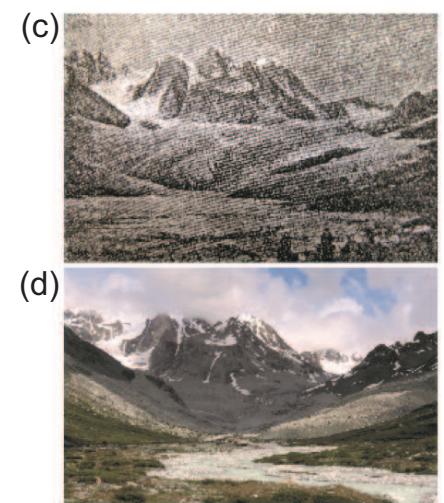
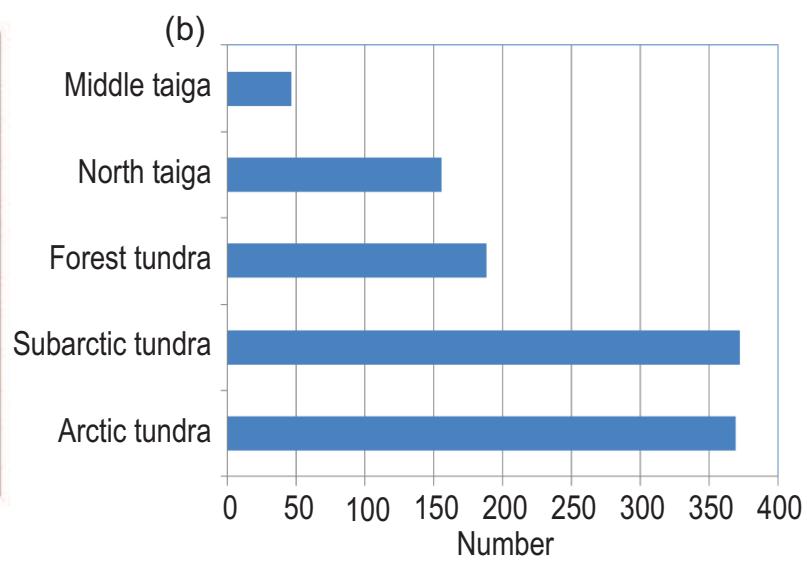
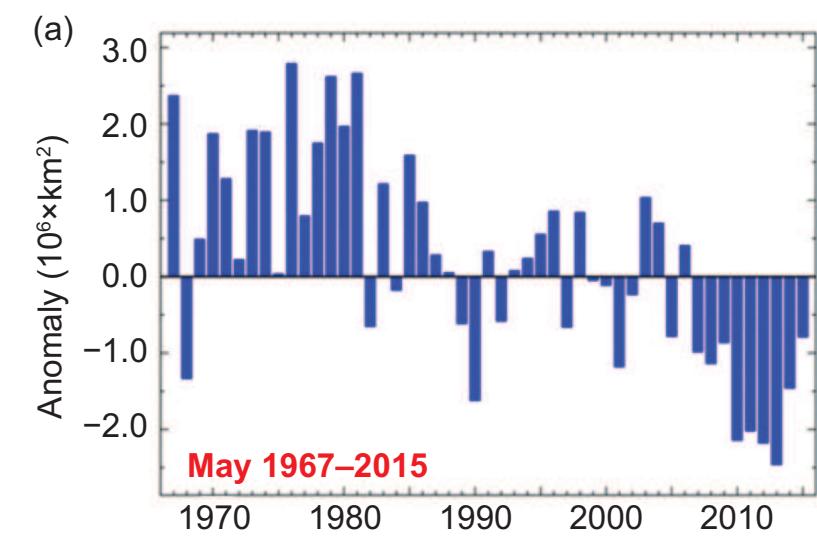
[Click here to download Figure Figure\\_05-final.eps](#)

Figure 6

[Click here to download Figure Figure\\_06-final.eps](#)



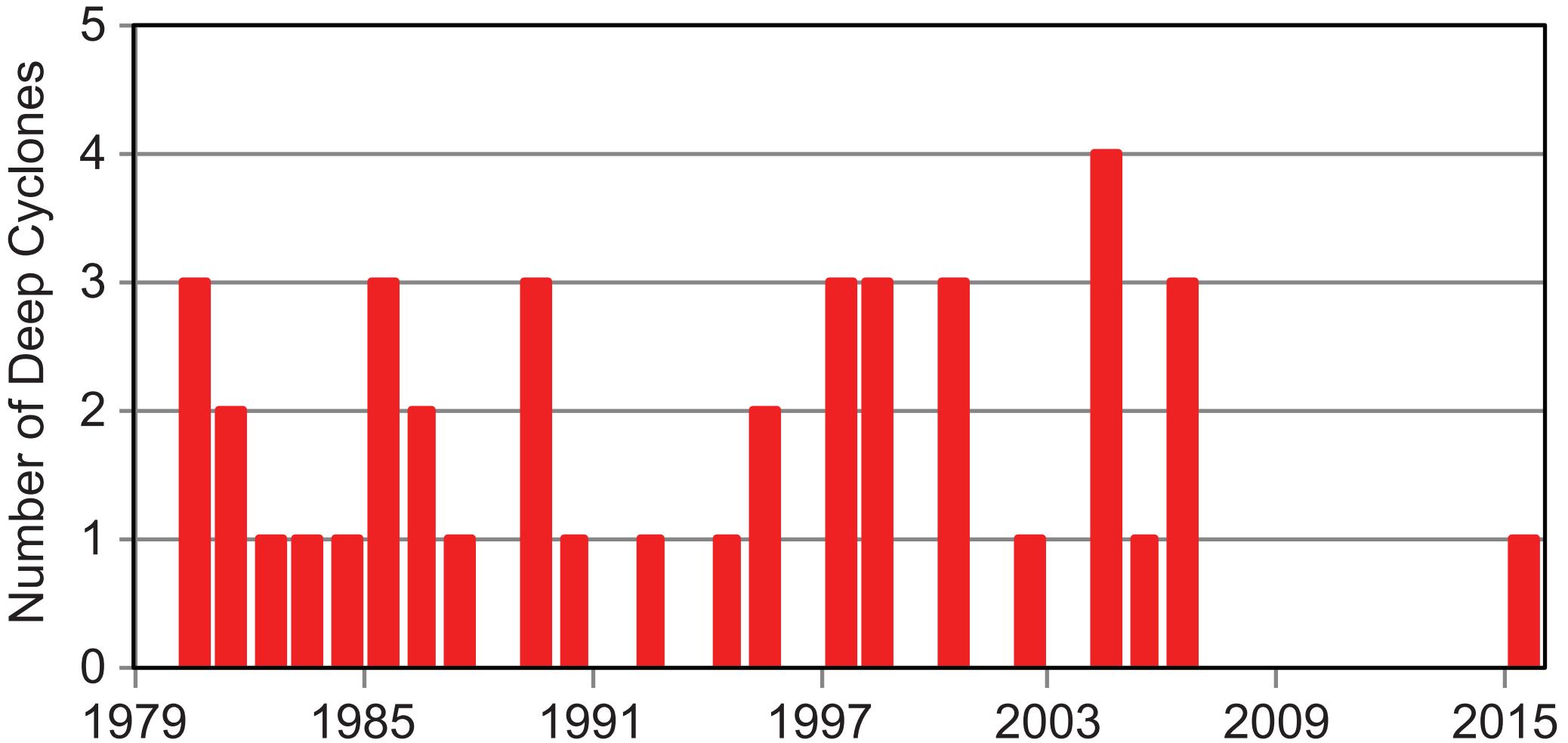


Figure 9

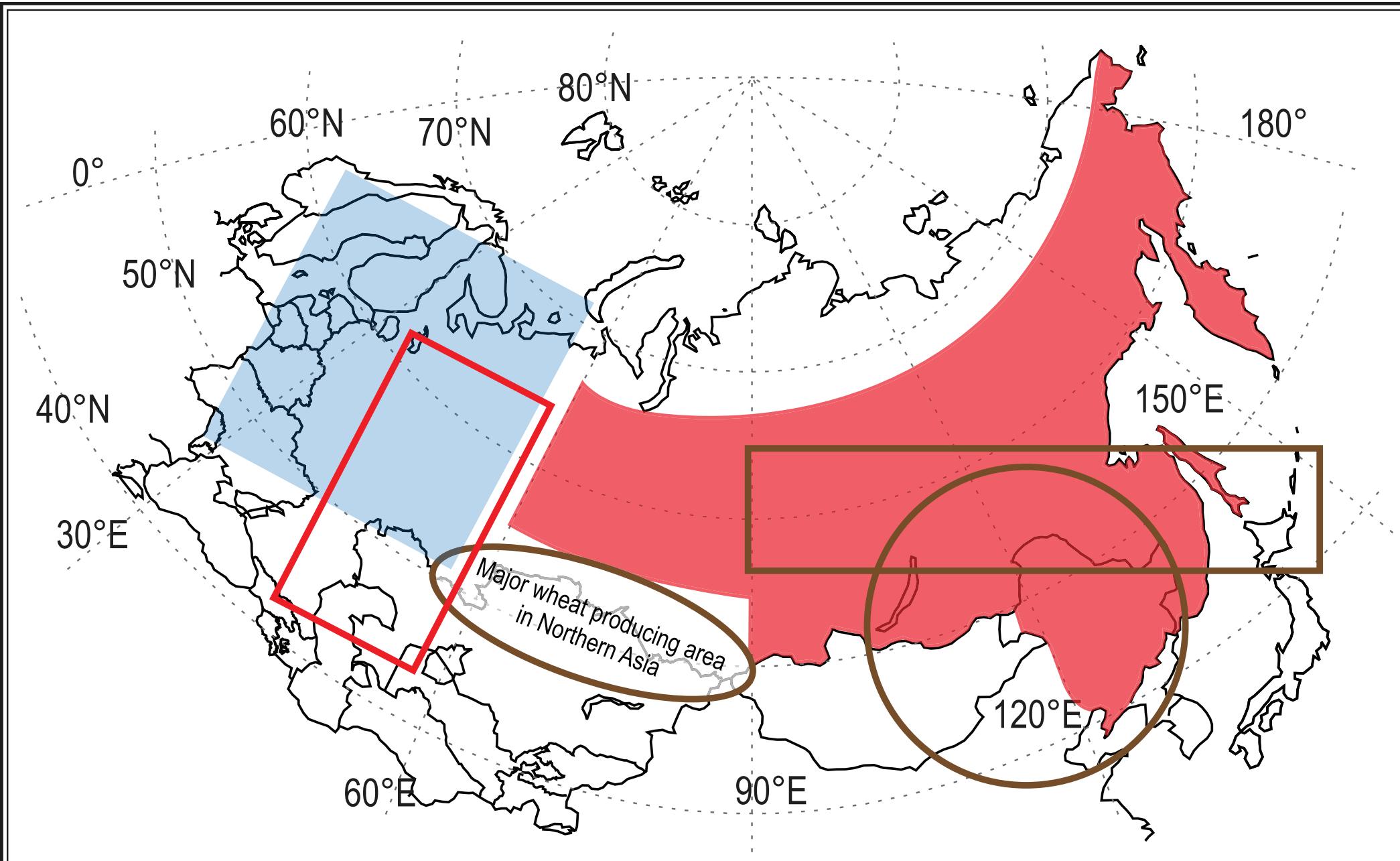
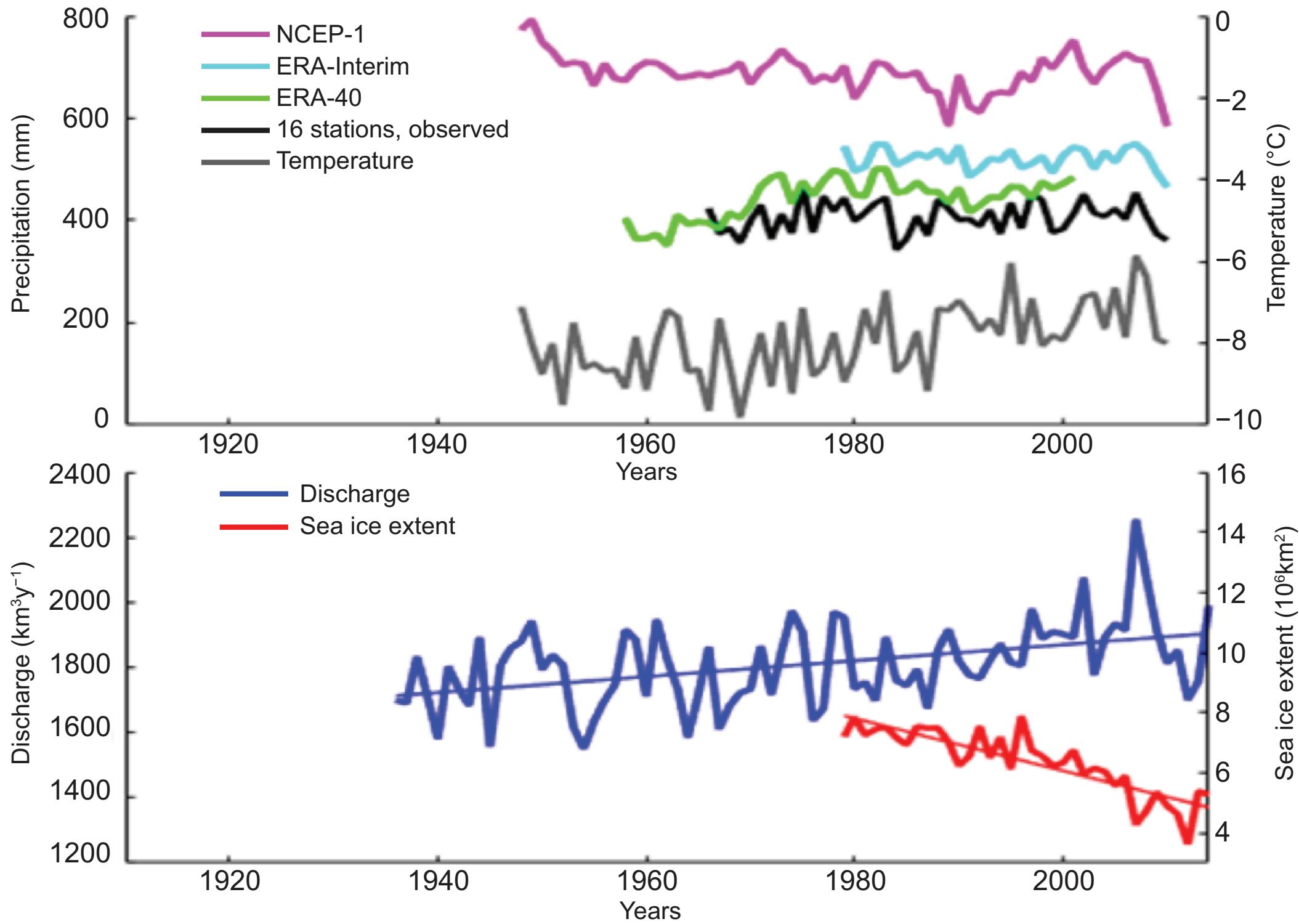
[Click here to download Figure Figure\\_09-improved.eps](#)

Figure 10

Click here to download Figure Figure\_10-final.eps



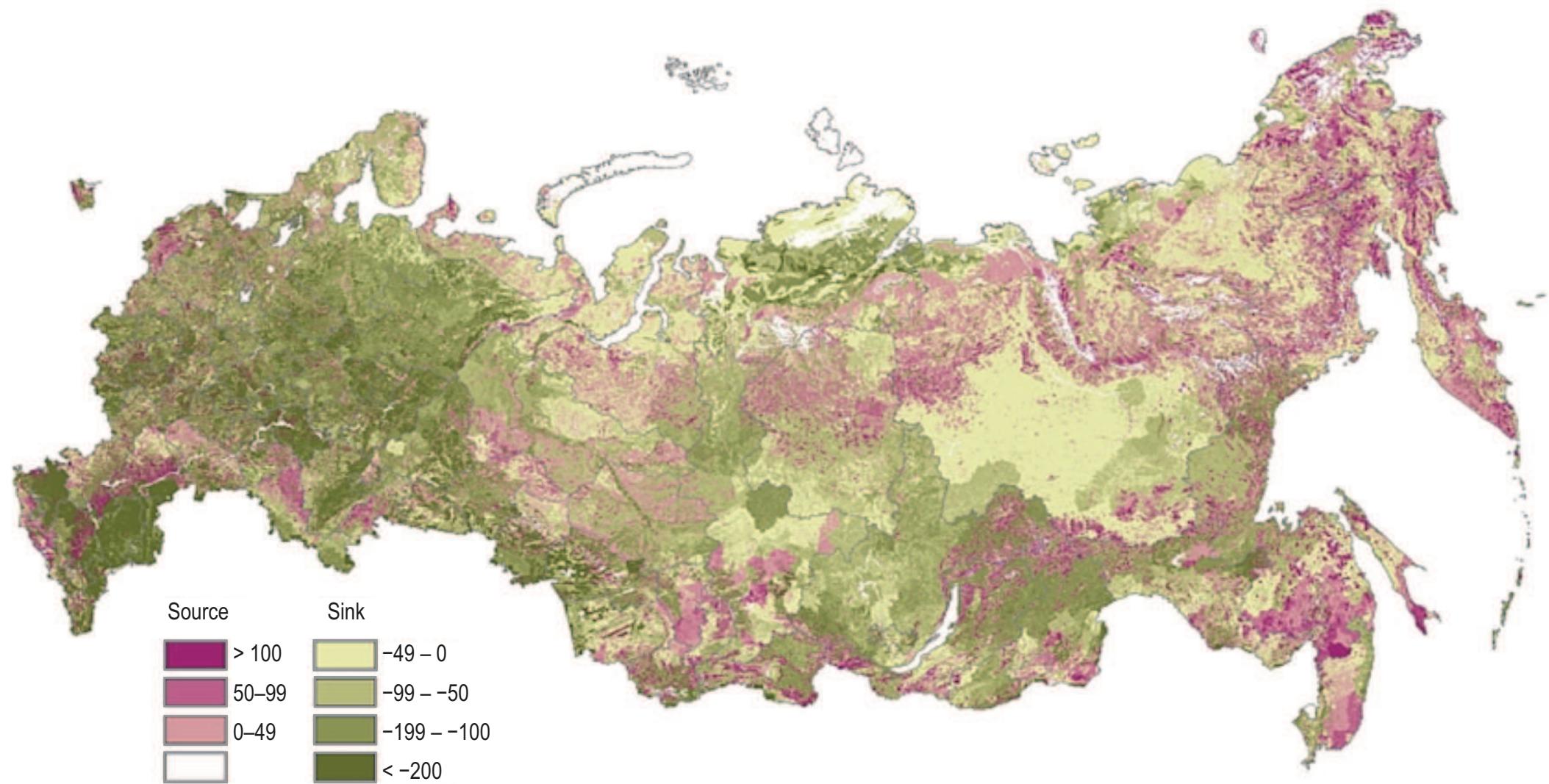


Figure 12

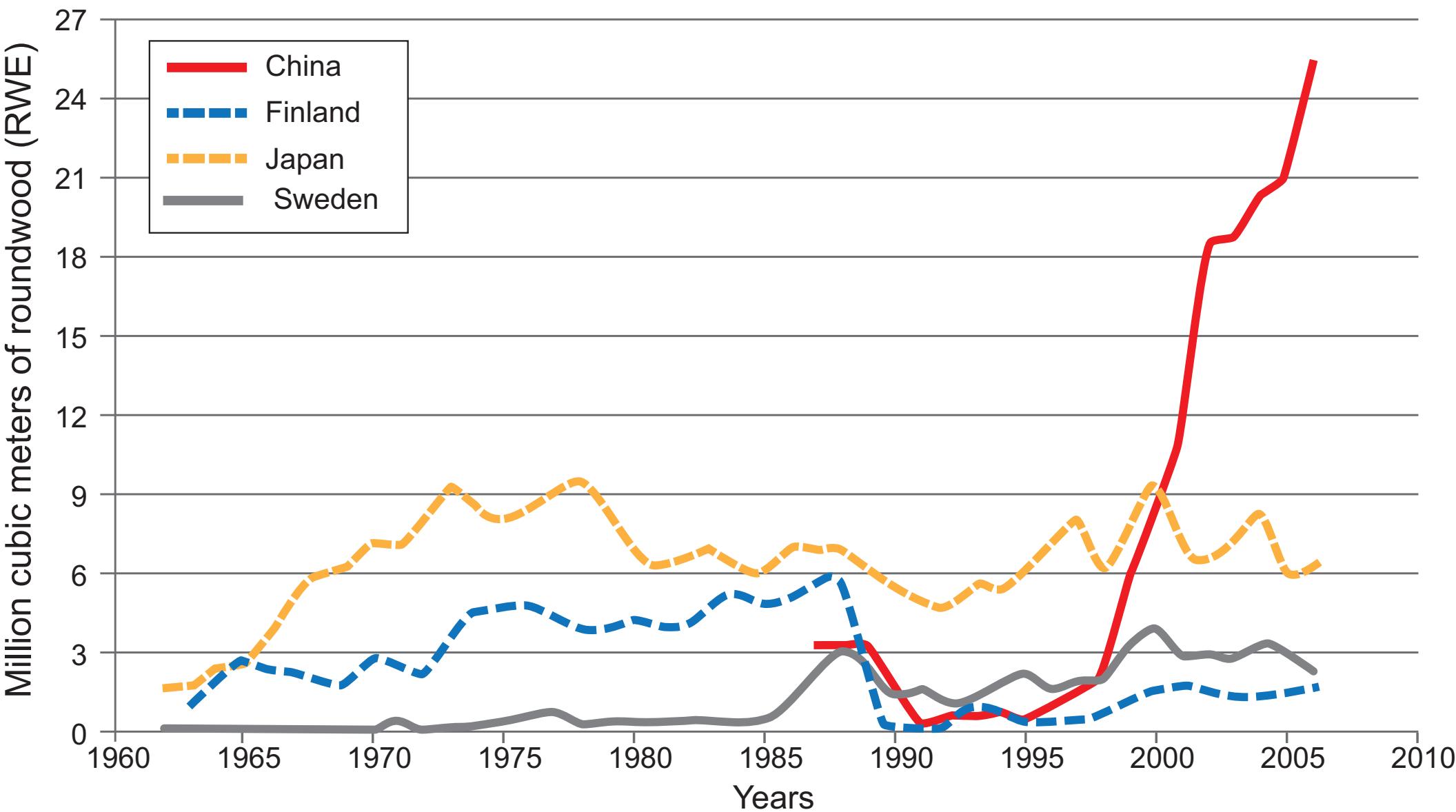
[Click here to download Figure Figure\\_12-final.eps](#)

Figure 13

Click here to download Figure Figure\_13-improved.eps

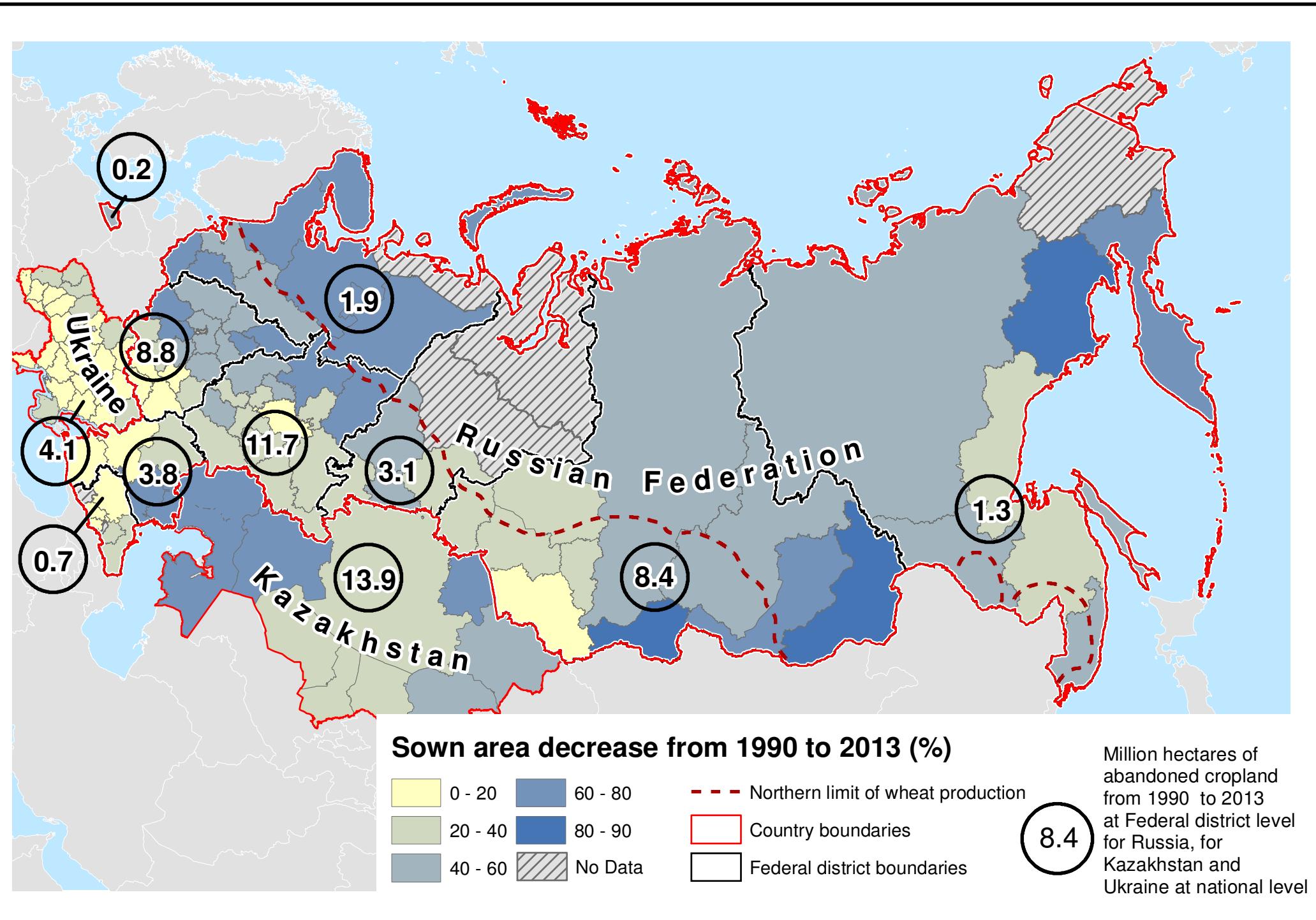


Figure 14

Click here to download Figure Figure\_14-final.eps

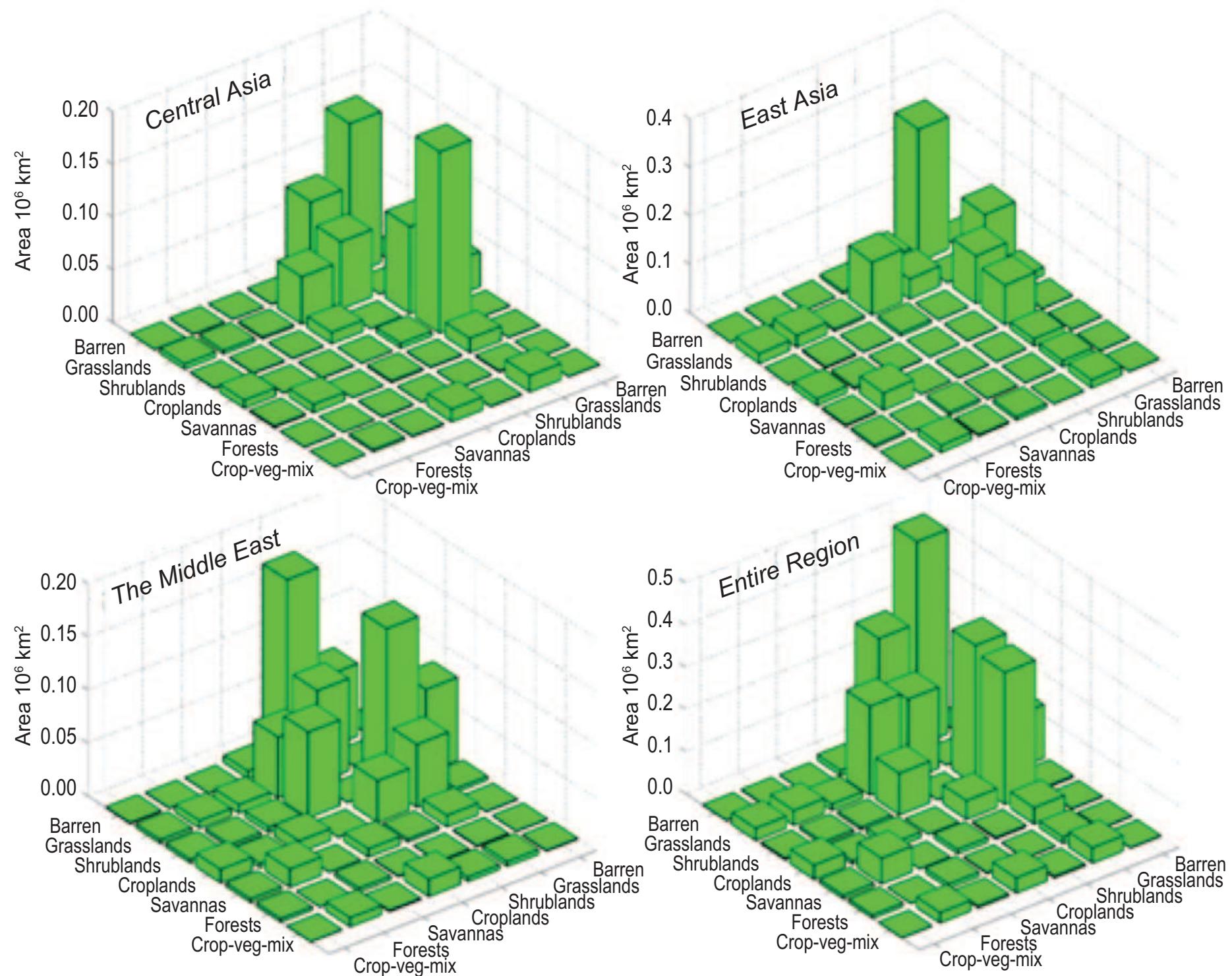


Figure 15

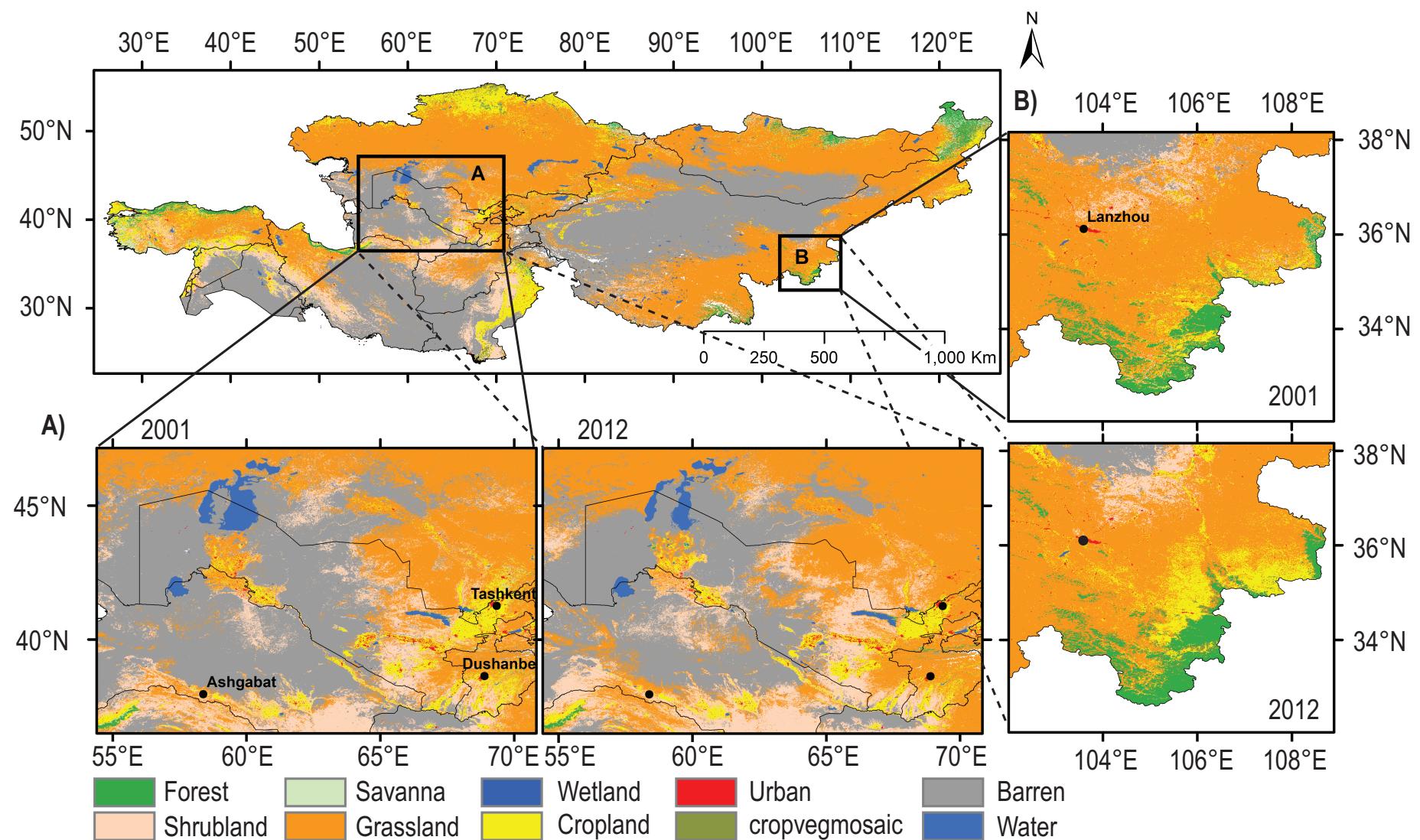
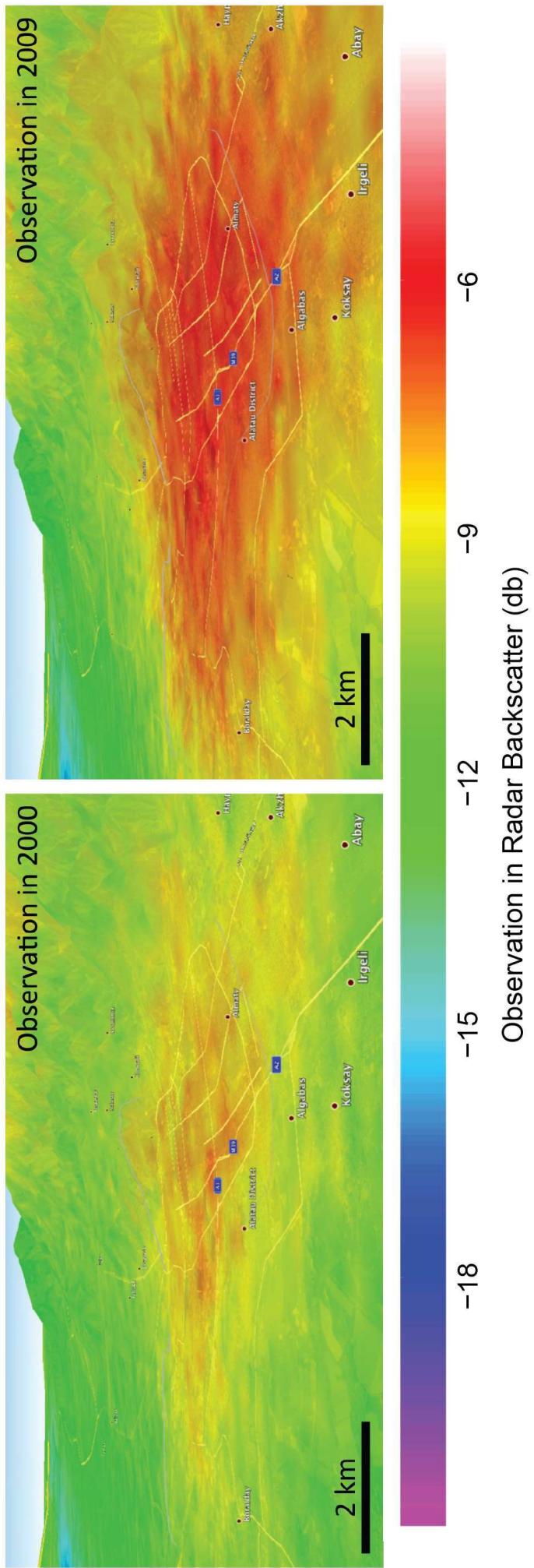
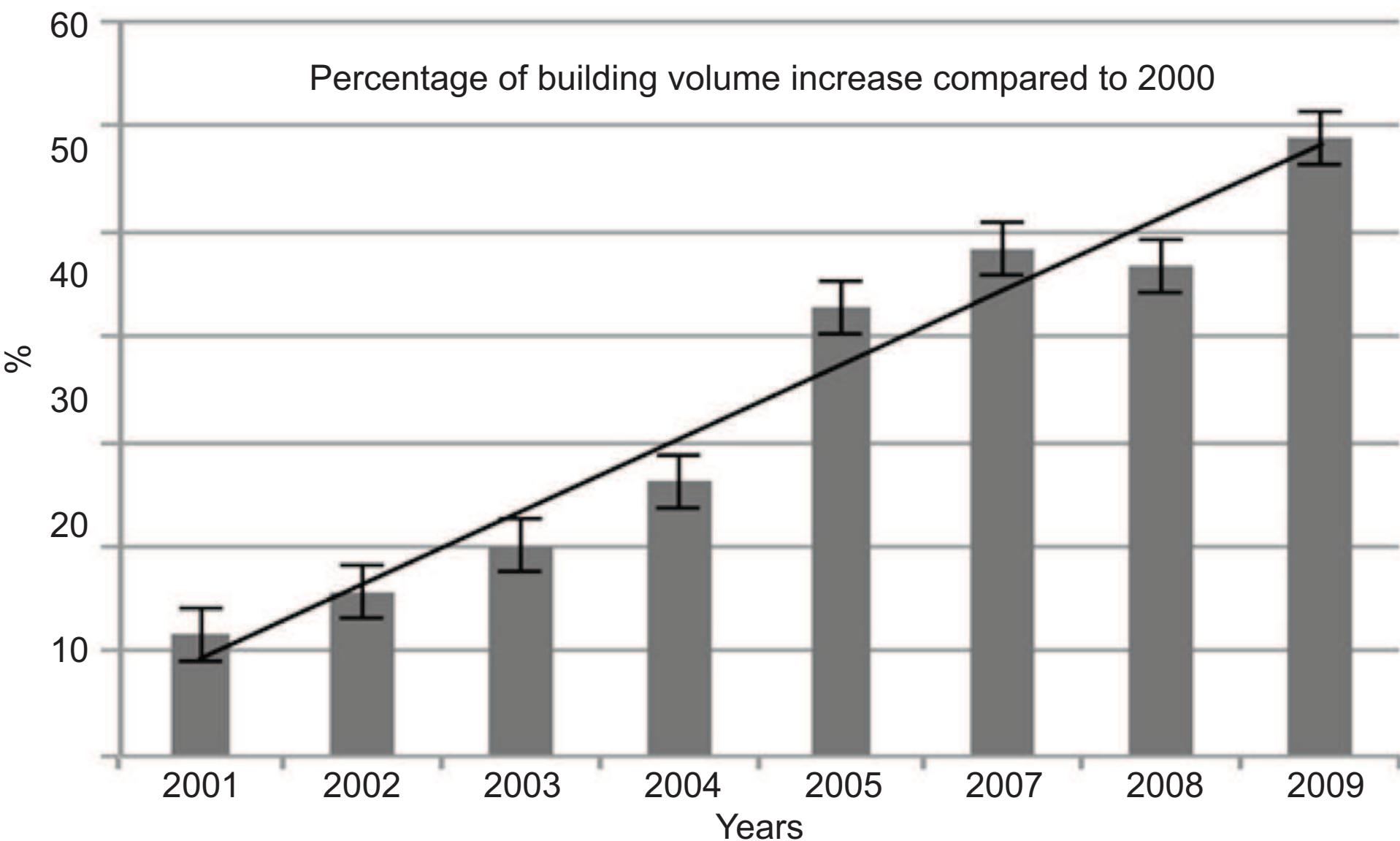
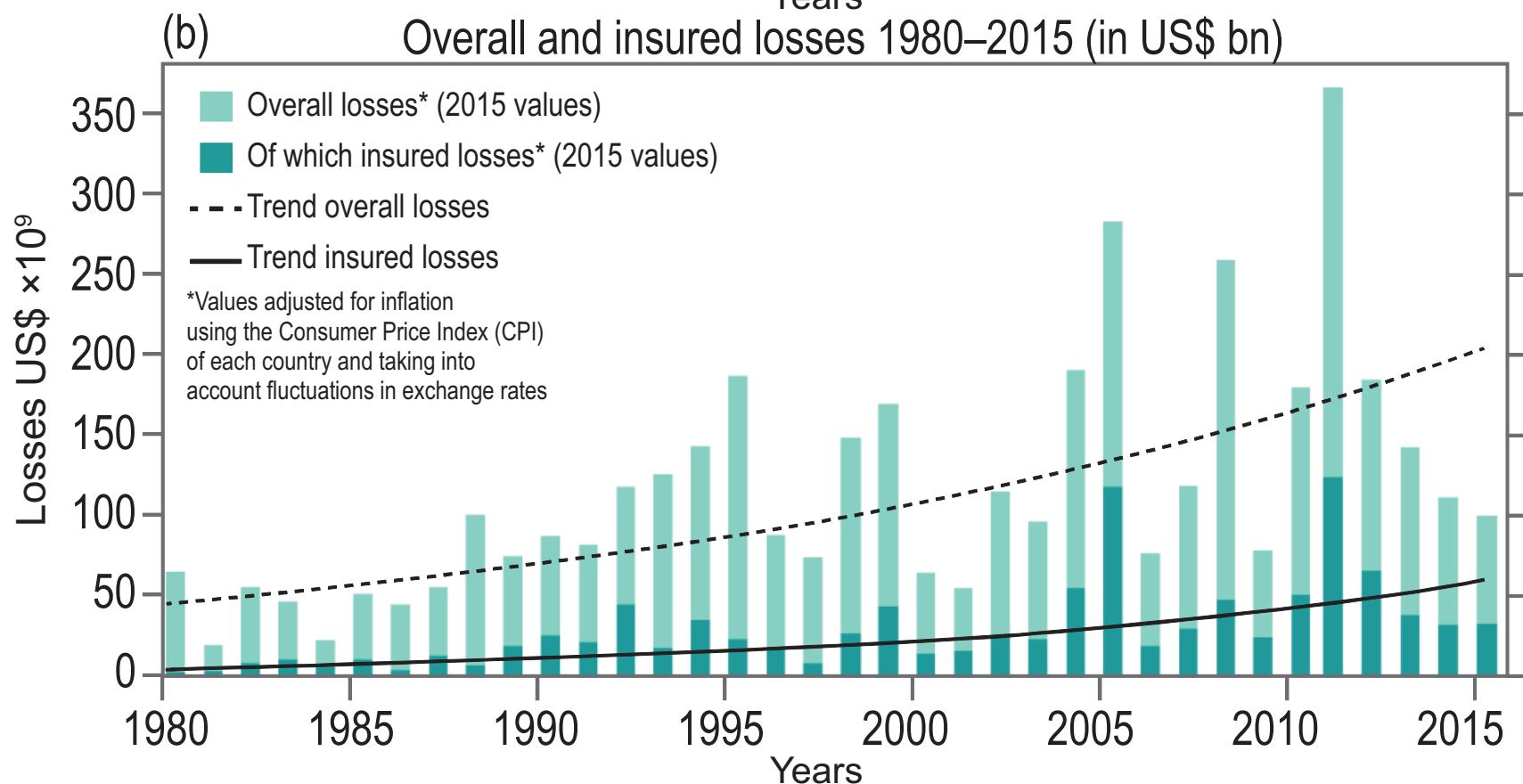
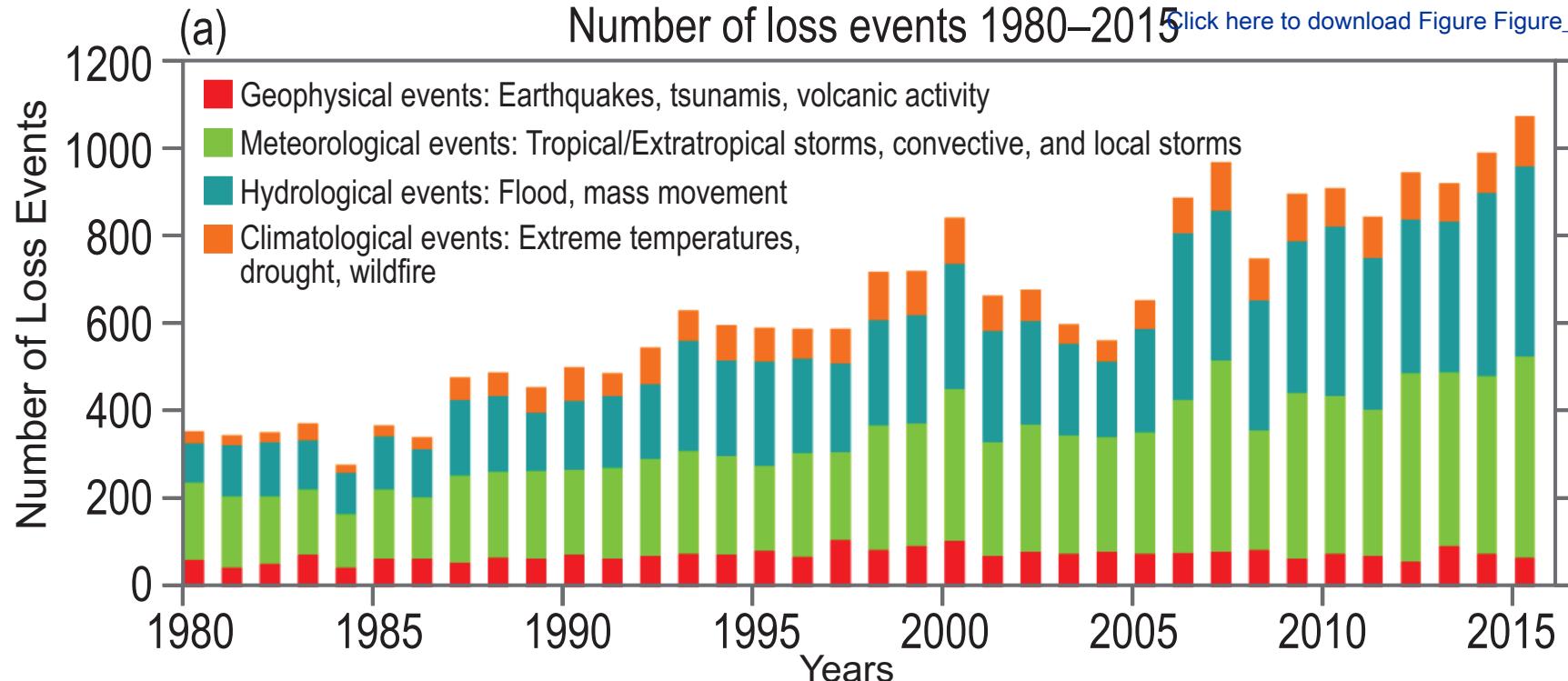
[Click here to download Figure Figure\\_15-v3.eps](#)

Figure 16

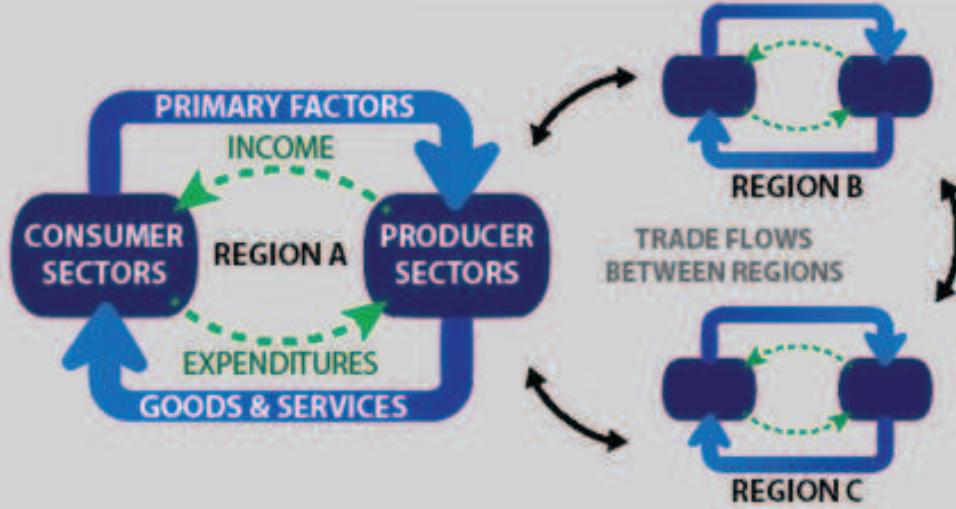
Click here to download Figure Figure\_16-final.eps



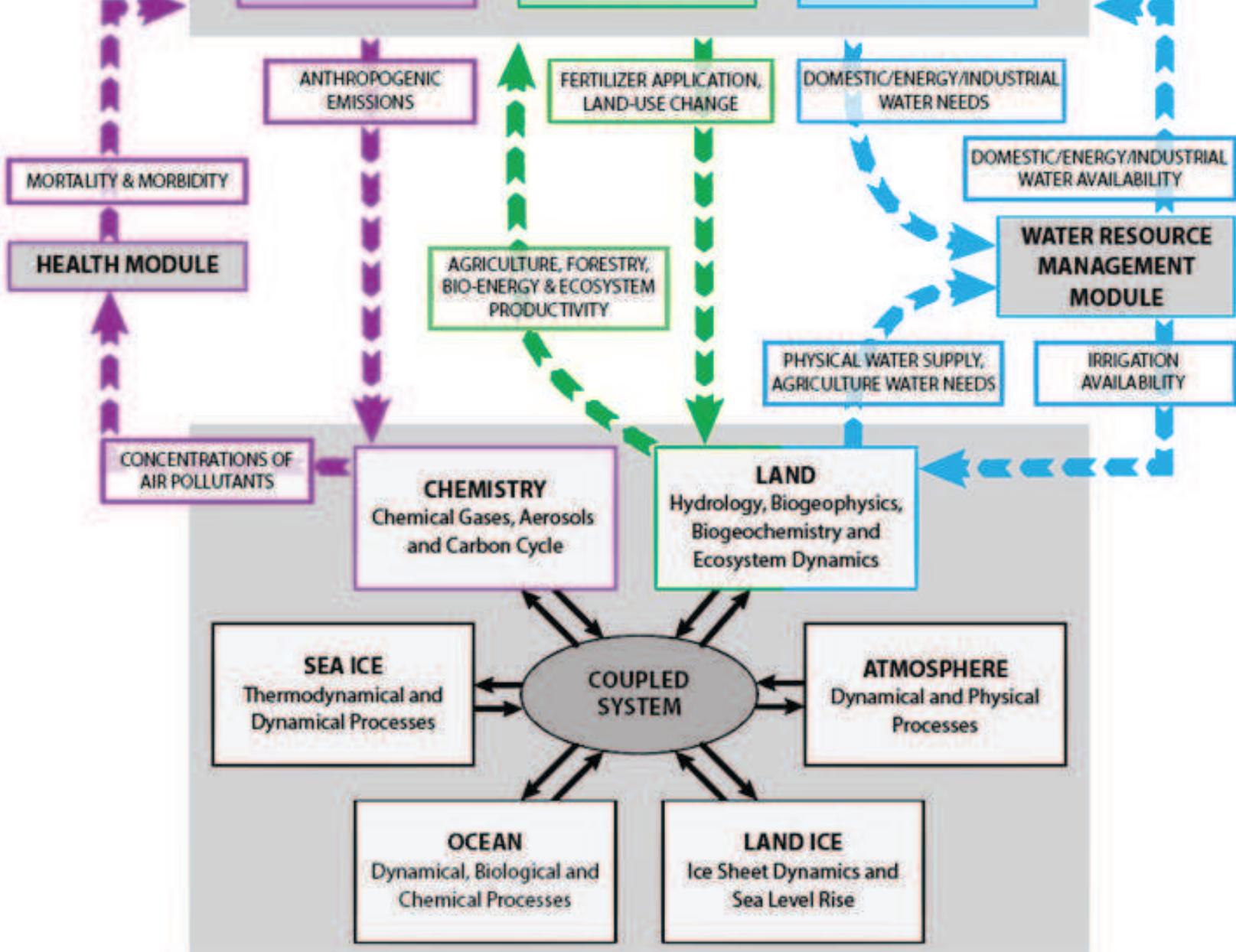




# HUMAN SYSTEM



## HUMAN HEALTH PATHWAY    LAND-USE CHANGE PATHWAY    WATER USE PATHWAY



# EARTH SYSTEM

